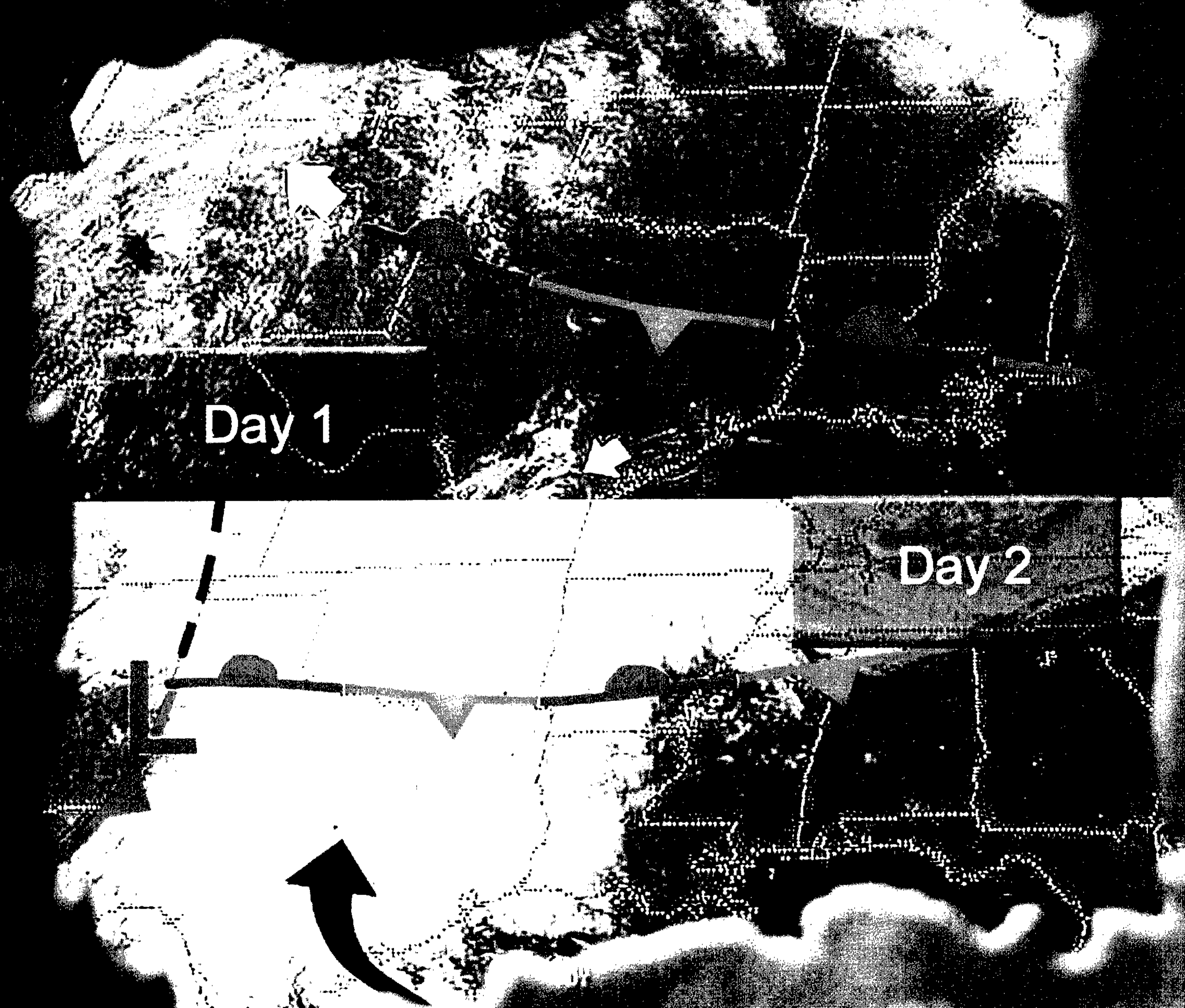
AFWA/TN-01/002
1 December 2001

WINTER REGIMES



EUGENE M. WEBER
Air Force Weather Agency
Offutt Air Force Base, Nebraska 68113

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Wendell T. Stapler

WENDELL T. STAPLER, Lt Col, USAF
Director of Air and Space Sciences

John D. Gray

JOHN D. GRAY,
Scientific and Technical Information
Program Manager

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13. Abstract: This technical note presents a back-to-basics approach to forecasting the weaker, slower moving weather systems of summer. It is especially designed for new and inexperienced forecasters, but it is also an excellent review for all forecasters. As summer approaches, the subtropical ridge begins to drift northward across the southern United States. The increasing insolation, moisture, and weakening pressure and thermal gradients require forecasters to apply different forecasting rules. This technical note presents synoptic patterns and regimes that routinely occur during the summer months. Synoptic pattern recognition is still one of the most important considerations when producing a forecast and will help in determining if model guidance is "on track."

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PREFACE

This Technical Note is the second of the four Forecaster Memos (FMs) being revised and updated with later model guidance and satellite images. These FMs seasonal weather patterns were originally published by Third Weather Wing (3 WW) in the early 1980s.

The information presented within this Technical Note is a cumulation of weather information that I have gained over 27 years as an Air Force weather forecaster, and after retirement, 16 years as a Civil Service Lead Forecaster in the Severe Weather Section of the AFGWC, and now AFWA's Production Floor.

Considerable knowledge was gained over the 16 years in the Severe Weather Section while observing weather conditions across the continental United States in preparation of the Military Weather Warning Advisories (MWAs) and also the issuance of Point Weather Warnings (PWWs). Certain weather patterns (regimes) for each season routinely occurred. A seasoned forecaster can spot evolving weather events across the country using their analysis package, satellite and model guidance.

The information that will be presented pertains to analyses, satellite interpretation and empirical rules. Some empirical information was extracted from my 3 WW publications: *Gulf Moisture Advection*, *Major Midwest Snowstorms*, *Satellite Interpretation*, and *Freezing Precipitation*. Some of the information dates back to the 1970s; however, "weather is weather" and events that occurred 30 years ago will repeat and repeat into the future. New methods and equipment to help forecasters has changed dramatically through the years. There has been an explosion of auxiliary weather information within the past few years through the Internet. So much weather data is available through the National Weather Service and many universities.

Very little model-forecast data will be presented. The intent behind the absence of model guidance is to show that forecasters can produce short-term forecasts on their own by analyzing charts and interpreting satellite data. As mentioned above, there is so much model data available that one can become confused as to what product is best. Forecasters who become comfortable in analyses and satellite interpretation will have little trouble in initializing the zero hour model packages. The empirical rules that will be presented have been developed from many case studies throughout the years. These rules are intended as tools for synoptic pattern recognition of the potential for winter storm regimes and their associated weather.

This Technical Note was written in a common sense "back to basics" approach and has been especially designed for new and/or inexperienced forecasters. Also, it should be an excellent review for all forecasters for the upcoming winter season. The Technical Note is basically composed of synoptic patterns and regimes that routinely occurred during the winter months. Although, winter officially begins in mid-December by the calendar date, I have included weather information and case examples for November since winter weather occurs often during this month. Synoptic pattern recognition is still one of the most important considerations when producing a forecast and will help in determining if model guidance is "on track." Hopefully, I believe this Technical Note will help future forecasters for years to come regardless of any new numerical model improvements and/or new systems that will come on line.

ACKNOWLEDGMENTS

Special acknowledgments goes to Air Force Weather Agency's Commander and senior Staff for funding and allowing me to continue part-time writing and publishing Technical Notes (after Civil Service retirement). This part-time position is managed through Science Applications International Corporation (SAIC).

A special thanks goes to Mr. Thomas K. Klein Sr., (Col, USAF-Ret), Offutt SAIC Site Manager, and Mr. Paul Demmert (Maj, USAF-Ret) for their advice and encouragement during this transition from operational weather forecasting to research and writing as part of AFWA's DNTT section.

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Special thanks goes to Mr. Mike Jimenez (SMSgt, USAF-Ret), HQ AFWA/DNTT, for the final editing and formatting, graphics support, and advice in getting this Technical Note ready at AFWA for desktop publishing at the Air Force Combat Climatology Center (AFCCC).

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Thanks goes to AFWA's Severe Weather Section, especially Mr. Ed Lachowicz and Mr. Vernon Nosal for saving satellite data that was used throughout this publication.

Finally, I acknowledge my wife, Doris, for continued understanding of my interest in my profession even after retirement.

EUGENE M.WEBER

Winter Regimes
Chapter 1

Introduction

In Air Force Weather (AFW), a regime is defined as "a specific synoptic and/or mesoscale weather pattern that affects the local weather at a particular location." Weather regimes occur at all scales of motion; however, the dominant local effects are usually associated with the synoptic scale weather pattern (highs, lows, fronts, etc.). In some cases, significant local effects are associated with mesoscale patterns (low-level jets, cold air damming, land/sea breezes, etc.). As autumn turns to winter, synoptic regimes and the resulting weather conditions often change drastically. The polar jet gradually shifts southward and suddenly forecasters find the mild, dry Indian summers of autumn replaced by the frequent passages of storm systems followed by blasts of cold polar air. Forecasters should be constantly aware that significant changes would occur within a 24-hour period such as shown in the cover figure. In the top figure, the weather conditions are quiet over the Great Plains. A tongue of Gulf moisture is shown over southern Texas. A Pacific short wave is noted over the western CONUS. An east-west polar stationary front lies across the central Great Plains (not shown). Within 24 hours, bottom figure, a major storm has developed over the Great Plains as Gulf moisture overran the stationary front and interacted with the Pacific short wave. Freezing rain and heavy snow fell over the central and upper Great Plains.

Upper Levels

General Circulation

The general circulation continues to strengthen throughout the period. A southerly shift of the westerlies continues and by mid-winter the polar jet often lies across the southern CONUS, Mexico and adjacent water areas (Figure 2-1). Storm systems track further south across the central and southern CONUS spreading a variety of winter's weather to those areas.

Figure 2-2, a GOES-E water vapor image (approximately five hours prior to Figure 2-1) shows jet stream locations in the vicinity of the dark areas (more discussion on jet stream placement will be presented later in this chapter.

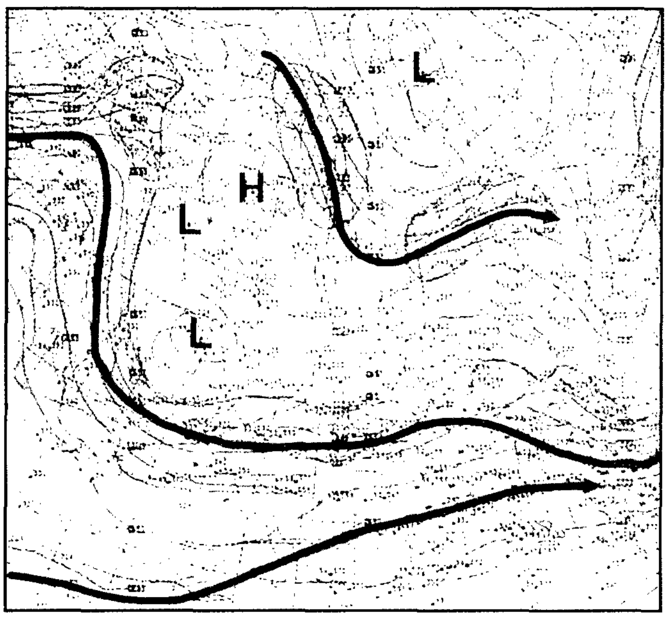

Figure 2-1. 250 mb, 0000Z/26 January 2001
Strong polar jet streams appeared over the southern latitudes by mid-winter.

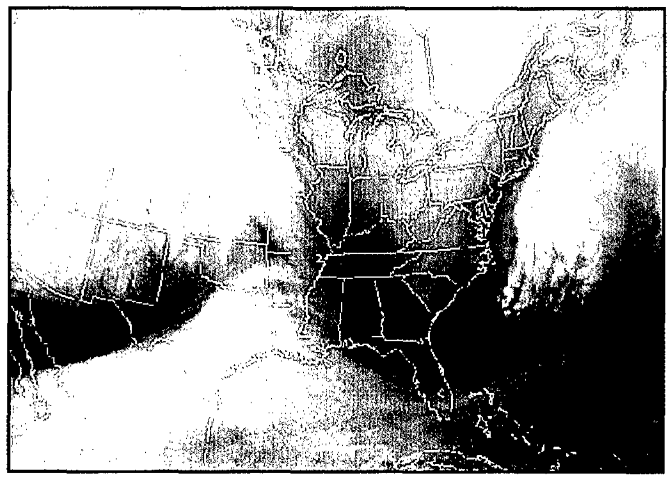

Figure 2-2. GOES-E Water Vapor, 1915Z/25 January 2001

Zonal Regimes

Zonal flow (high index) regimes occurred throughout the winter; short waves track eastward across the CONUS within this west to east upper flow (Figures 2-3 and 2-4). Pacific maritime polar fronts move eastward into the Great Plains and often interact with Canadian cP air masses.

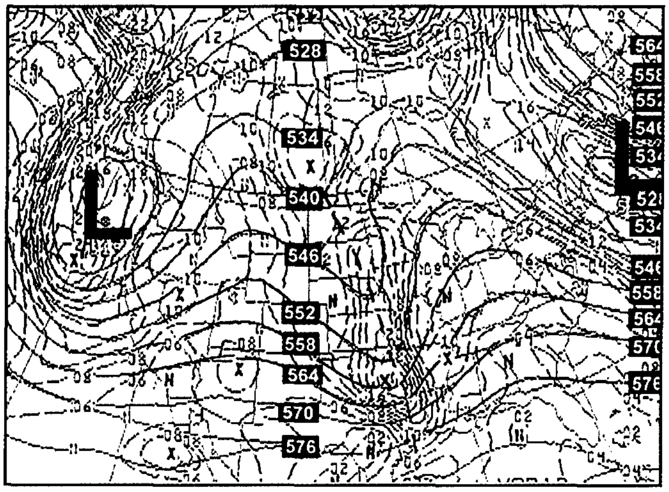

Figure 2-3. 00HR FCST 500 mb HEIGHTS/ VORTICITY, 19 January 1999
Short waves moving through zonal flow.

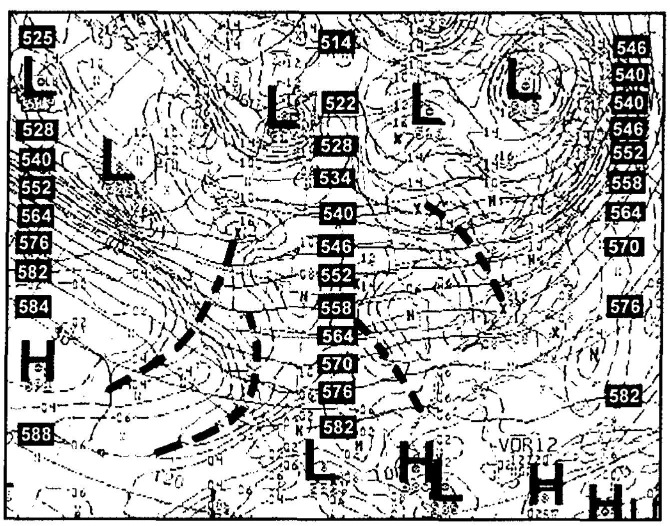

Figure 2-4. 24HR FCST 500 mb HEIGHTS/ VORTICITY, 20 January 1999
Vorticity isopleths reveal short waves moving through zonal flow (dashed lines).

As previously shown many Pacific short waves track across the CONUS. During the cold season, some of these short waves decelerate and undergo cyclogenesis within the trough over the western CONUS. Significant snowfall at the snow levels and above are likely as the system continues to strengthen; snowfall amounts are dependent on the availability of Pacific moisture advection. These developing systems often evolve into split flow events (will be presented in Chapter 3).

Figures 2-5 and 2-6 illustrate an example of trough cyclogenesis over the western CONUS. Weak contour and thermal gradients and cold air advection within the trough in conjunction with positive vorticity centers, height fall centers (HFCs) and jet stream maxima are good indicators of probable cyclogenesis. Figure 2-5 shows a typical 500 mb cyclogenesis configuration within a trough. Generally, the first clue is a widening of the contour and thermal gradients as shown over northern California and Nevada in Figure 2- 5. The hatched box shown in Figure 2-5 indicates a favorable area for cyclogenesis. Low development subsequently appears east to southeast of the hatched box and occurs north of the tighter contour and thermal gradients and the height fall center (indicated by the **X** in Figure 2-5; the dots identified height fall fields). Twenty-fours later in Figure 2-6, an upper low has developed over northern Arizona; the associated height fall center is noted over Albuquerque, New Mexico. In Figure 2-6, significant snow fell over the northern New Mexico Mountains and Colorado. This storm evolved into a major snowstorm over the central and northern Great Plains. Figures 2-5 and 2-6 depict a classic example. Conversely, not all troughs entering the West Coast that have the signatures for cyclogenesis shown will develop an upper-level low. However, a significant storm and precipitation may occur in the absence of an upper low. Model guidance is generally good in predicting if a low will develop within the middle and upper troposphere.

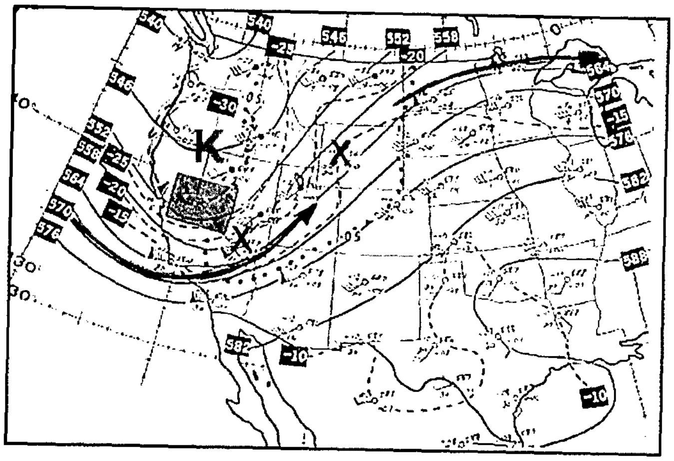

Figure 2-5. 500 mb, 0000Z/2 December 1973
Tighter contour and thermal gradients and jet speed max shown over central and southern California. Upper low formation looks favorable.

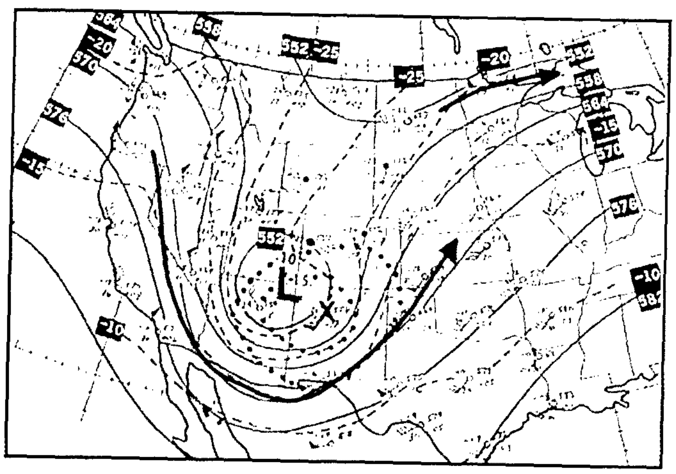

Figure 2-6. 500 mb, 0000Z/3 December 1973
Twenty-fours later, an upper low has developed southeast of the hatched area shown in Figure 2-5. This event has become a split-flow system.

Meridional Regimes

The other major winter regime (low index) that prevails, especially in January and February, is the meridional trough/ridge (long wave) pattern (Figures 2-7 and 2-8). Short waves move through these meridional trough systems as shown in Figures 2-9 and 2-10. Intense winter storms often develop. Further examples pertaining to zonal and meridional regimes will be presented throughout the rest of this Technical Note.

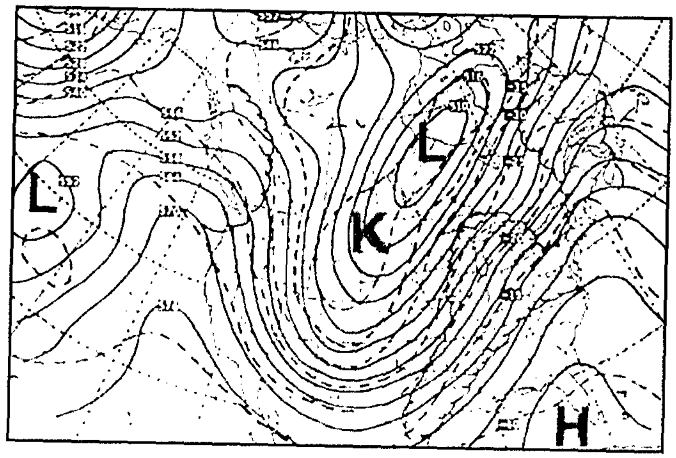

Figure 2-7. 500 mb, 0000Z/1 January 1979
Large-scale meridional trough/ridge systems.

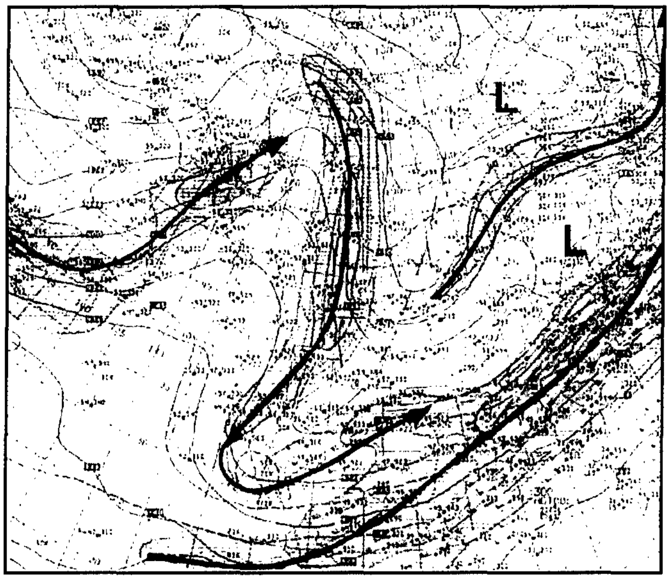

Figure 2-8. 300 mb, 0000Z/1 February 2001
Large-scale meridional trough/ridge systems and several polar jet branches.

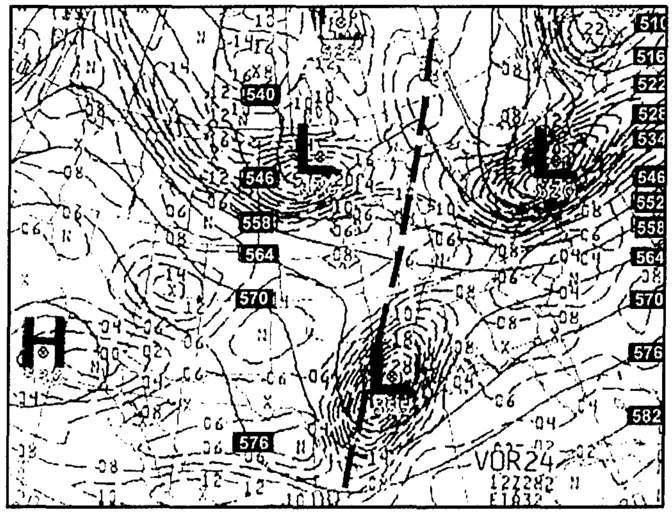

Figure 2-10. 24HR FCST 500 mb HEIGHTS/ VORTICITY, 1200Z/28 December 2000
Long wave (dashed line) was located over the central CONUS during most of December. Short waves were moving through the long wave.

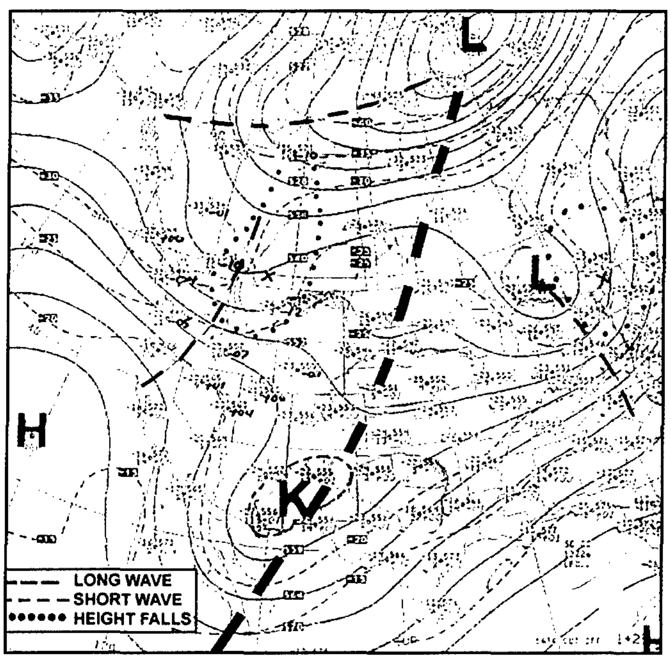

Figure 2-9. 500 mb, 1200Z/26 March 1987
Short waves moving through the long wave.

Meridional Regimes - Cold Core Low

A core cold low circulation is frequently observed over eastern Canada usually in the Hudson Bay area—a reflection of the long wave pattern over the colder landmass. Deviations east or west of this low circulation occur depending upon the total hemispheric pattern. Several lows are often noted within this large cyclonic feature. These lows are often associated with developing short waves moving southward from northern Canada (see arrow in Figure 2-11 and 2-12). Short wave lows rotate around the bottom of the circulation generally across the southern Hudson Bay area.

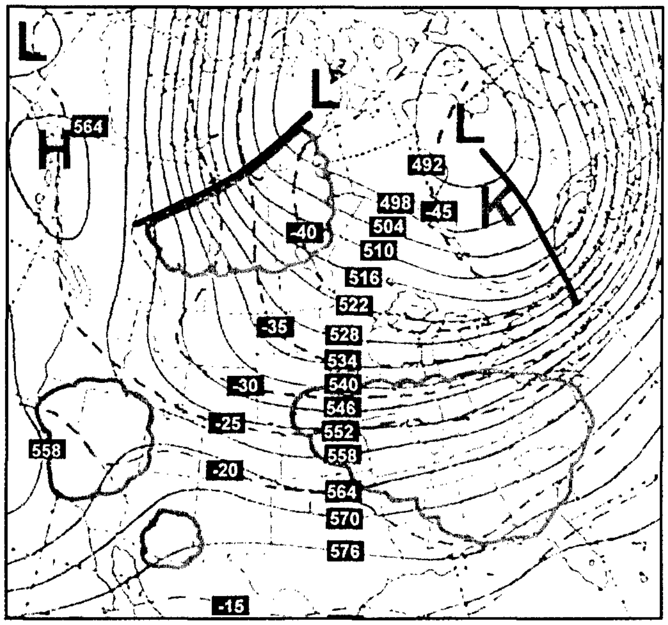

Figure 2-11. 500 mb 1200Z/5 January 1979
Cold core low over eastern Canada; short wave over northwestern Canada moving south.

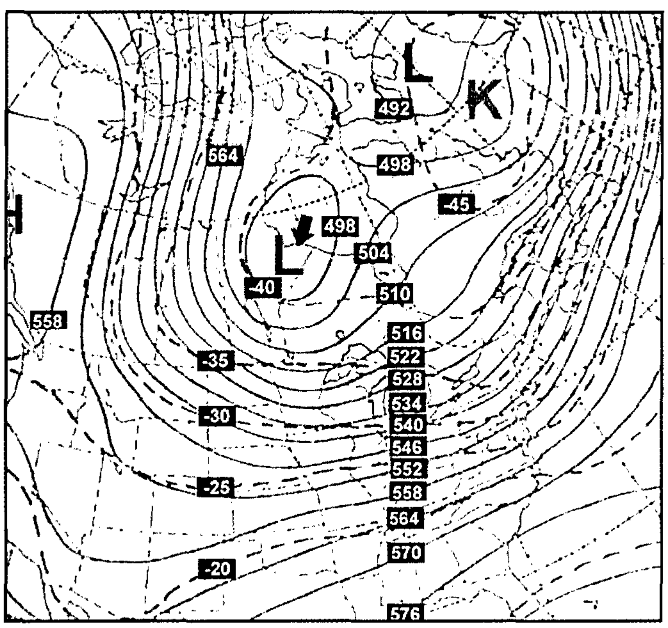

Figure 2-12. 500 mb, 1200Z/6 January 1979
Short wave low has deepened as it drops southward.

The cold core low described above may be displaced southward across southeastern Canada, the Great Lakes and New England as depicted in Figure 2-13 (not related to Figures 2-11 and 2-12). In Figure 2-13, the associated cold pocket is aligned east to west over the Great Lakes/northern Great Plains area. A warm pocket (noted by the W) appears over the Hudson Bay area. Rapid–moving short wave troughs moving through the long wave circulation often produce intense storms over the northern sections of the eastern CONUS. Strong cold air advection and surface winds, combined with extensive precipitation (mostly snow), will produce severe winter weather as in the case with this event.

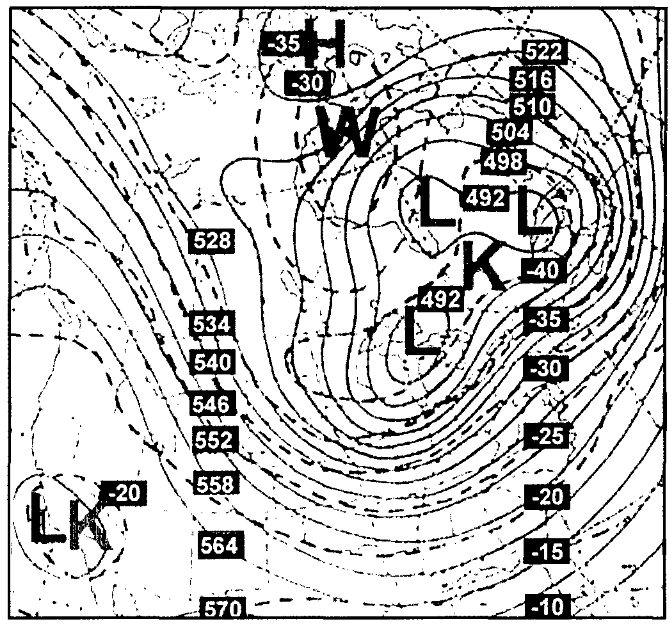

Figure 2-13. 500 mb, 1200Z/28 January 1977
The low over the Great Lakes produced severe winter weather.

Another example of the Hudson Bay cold core low being displaced southward from its normal location is shown in the following figures. In this early March event, a warm-core high-pressure system developed over the Hudson Bay region (see arrow in Figure 2-14) which shifted the low over Hudson Bay southward over the Great Lakes area. Additionally, in Figure 2-14, a short wave appears over the Lower Mississippi Valley. In Figure 2-15, a coastal low is shown along the Carolinas coast and is associated with the southern short wave. A deep thickness cold pocket marked by the **K** is located over the northern Great Lakes and is associated with the low over the upper Great Lakes as shown in Figure 2-14. No low pressure system appears at the surface in conjunction with this upper low; instead, an inverted trough is noted. The combination of these two systems produced a severe winter storm over the northeastern CONUS (see merging height fall centers in Chapter 6).

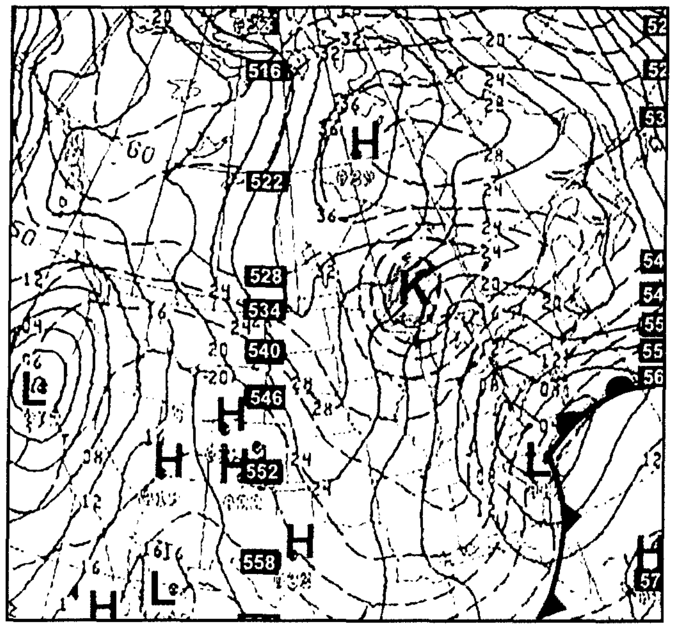

Figure 2-15. ANALYSIS MSL PRES/1000-500 mb THKNS, 0000Z/5 March 2001

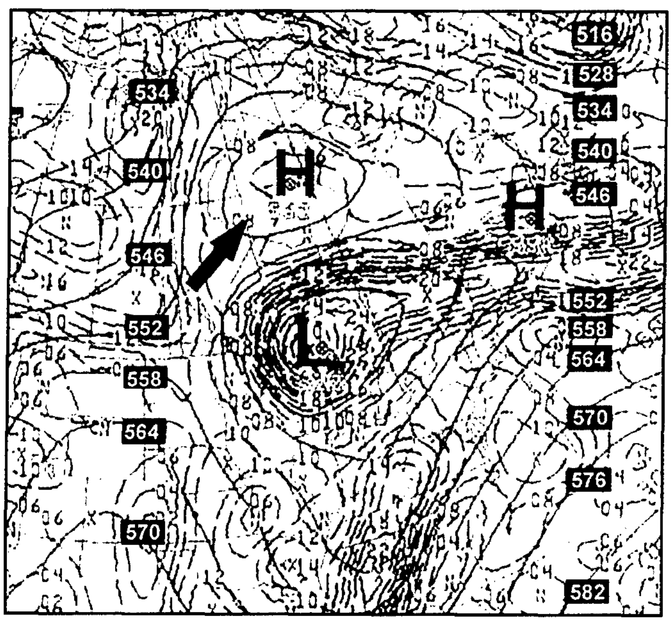

Figure 2-14. 500 mb ANALYSIS HEIGHTS/ VORTICITY, 0000Z/5 March 2001
Black arrow notes building high pressure system.

Figures 2-16 and 2-17 depict events thirty-six hours later from Figures 2-14 and 2-15. In Figure 2-16, the upper ridge is still in place over the Hudson Bay region (noted by the arrow). The low over the Great Lakes moved southeastward while the southern short wave moved northeastward and both merged over the Atlantic Seaboard. In Figure 2-17, a large storm system developed over the eastern CONUS as a result of the merger. Notice in Figure 2-17 that the thickness cold pocket (**K**) has dropped southeastward from the Great Lakes area and now appears over Virginia in association with the upper low. Strong surface winds along with significant snowfall occurred over the northeastern CONUS (within the deformation cloud zone of the large comma).

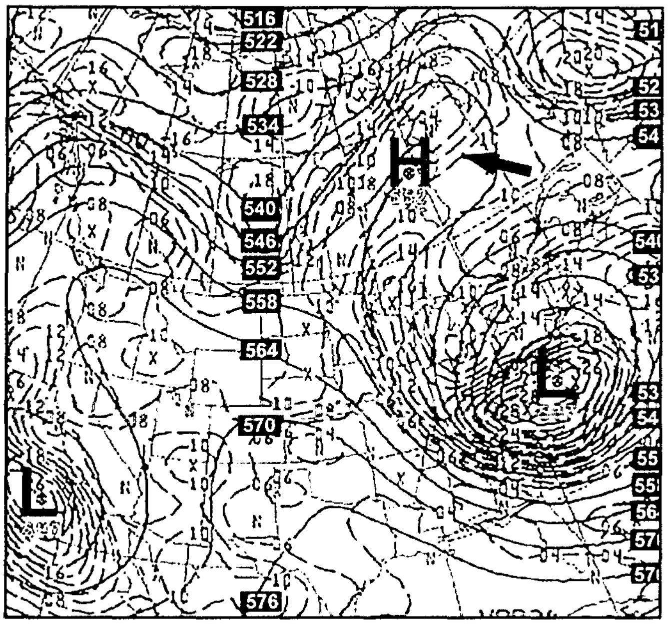

Figure 2-16. 500 mb 36HR FCST HEIGHTS/ VORTICITY, 1200Z/6 March 2001

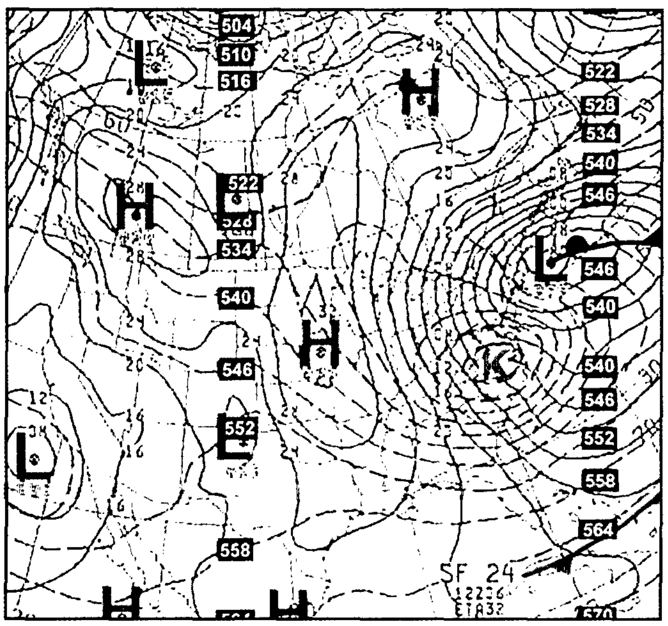

Figure 2-17. 36HR FCST MSL PRES 1000/500 mb THKNS, 1200Z/6 March 2001

Figures 2-18 and 2-19 illustrate the satellite images during its development (Figure 2-18) and in its occluded mature stage (Figure 2-19). In Figure 2-19, the deformation cloud system extends westward across New England – moderate to heavy snowfall occurred across the region.

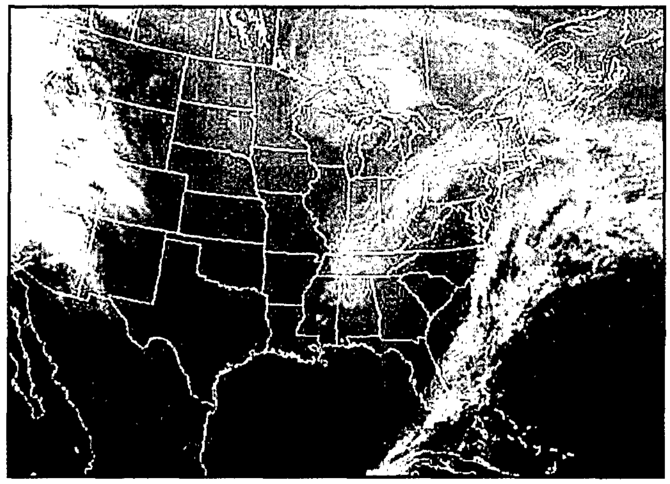

Figure 2-18. GOES-E IR, 0015Z/5 March 2001
Image same valid time as Figures 2-14 and 2-15.

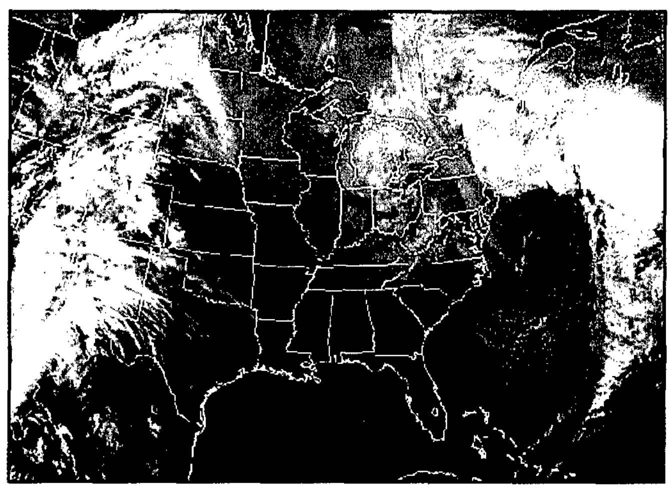

Figure 2-19. GOES-E IR, 0015Z/6 March 2001
Twenty-fours later than Figure 2-18.

The long wave trough/ridge regime shown in Figure 2-20 may persist for several weeks. A long wave ridge is in place over the eastern Pacific Ocean and along the Pacific west coast from southern California northward to Alaska as shown in Figure 2-20. This is a prolonged dry period for most of the western CONUS. Lows tracking across the Pacific Ocean are blocked by the ridge; consequently, they move northward instead of eastward. Further to the east, the central and northern Great Plains are dominated by very cold Canadian air masses. Short waves and their associated surface cold frontal waves bring fresh cP air southward with each successive system. This is a dry period for the central and northern Great Plains; strong cold air advection winds, accompanied with light snowfall with frontal passage, generally occur. Conversely, the southern Great Plains and the eastern CONUS are located in the moist baroclinic cloud zone of the southern branch of the polar jet where surface lows develop along stationary fronts and become major storms over the eastern CONUS.

Figures 2-21 and 2-22 show two more typical long wave regimes. Notice in Figure 2-21 that the low over Hudson Bay shown earlier in Figures 2-12 through 2-13 is misplaced further to the southwest and a cold pocket is noted over Montana.

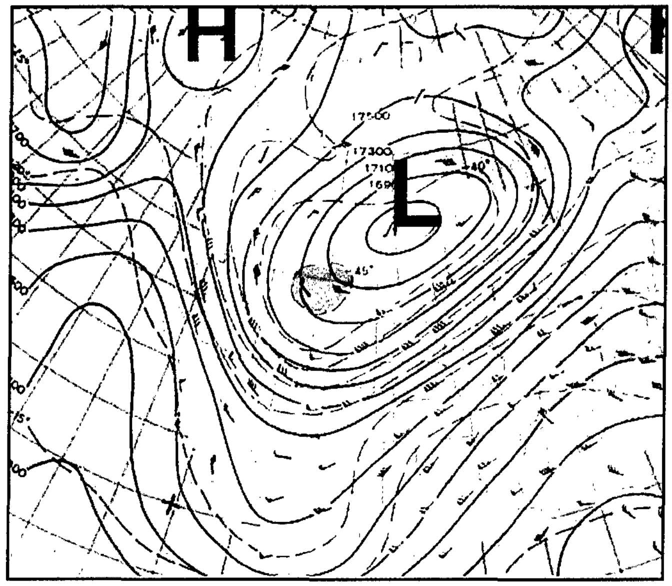

Figure 2-21. 500 mb, 1200Z/31 December 1978

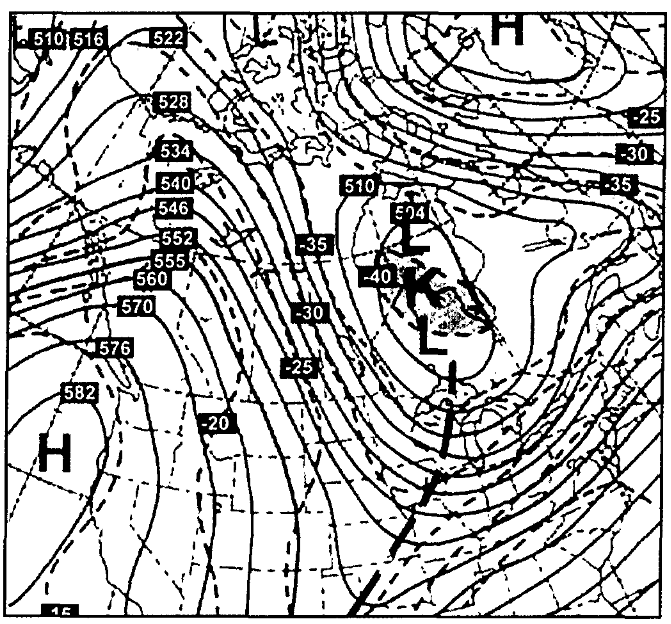

Figure 2-20. 500 mb, 0000Z/23 January 1980
Long wave trough/ridge pattern.

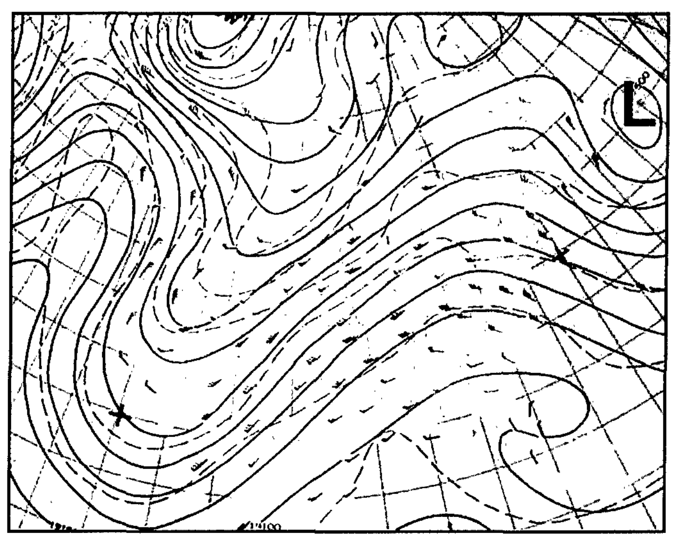

Figure 2-22. 500 mb, 1200Z/7 December 1980

Day-to-day continuity on the location and movement of these two primary upper-level features (zonal and meridional) and their associated surface systems is so important to determine primary cyclonic and anticyclonic tracks. For example, the eastern CONUS may be the "battleground" for cyclogenesis and precipitation for several days or even weeks Figure 2-23 and 2-24 and then retrogression shifts the battleground westward across the central and western CONUS seven days later (Figures 2-25 and 2-26).

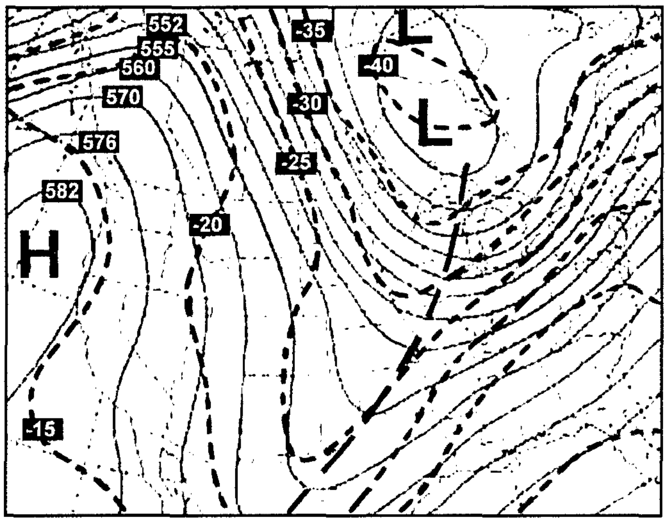

Figure 2-23. 500 mb, 0000Z/23 January 1980
Long wave (meridional) trough prevails over the central CONUS.

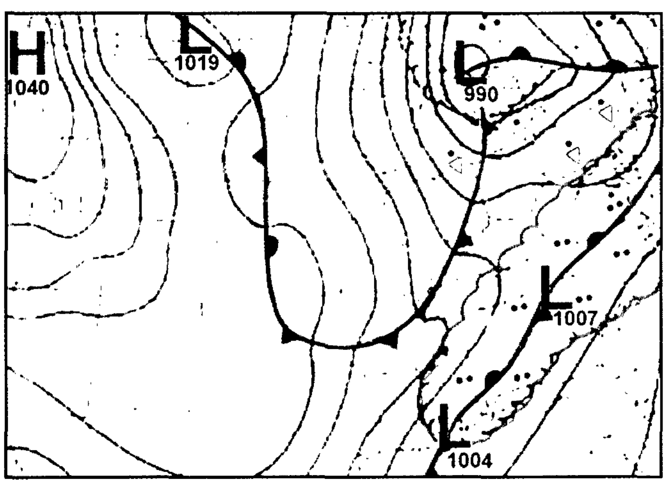

Figure 2-24. Surface, 0000Z/23 January 1980
Stationary polar front with precipitation shown over the southeastern CONUS. Dry Canadian cP cold front approaching stationary front.

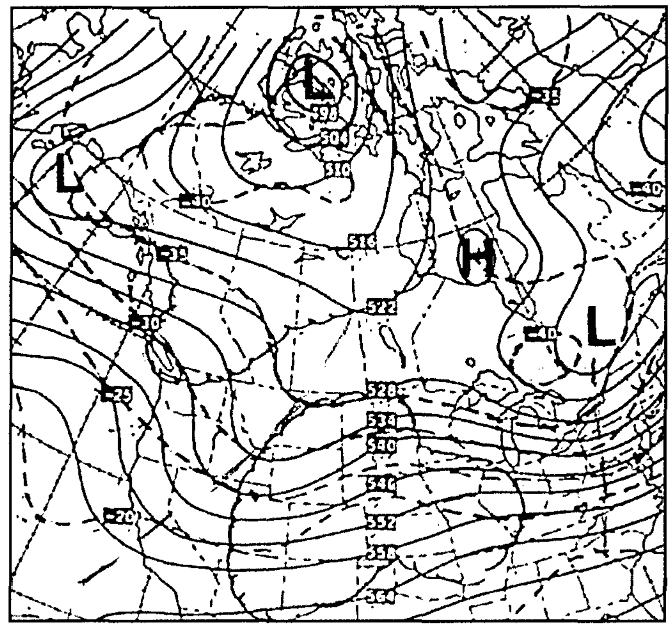

Figure 2-25. 300 mb, 0000Z/30 January 1980
Seven days later from Figures 2-23. Upper-level pattern changed from meridional to zonal.

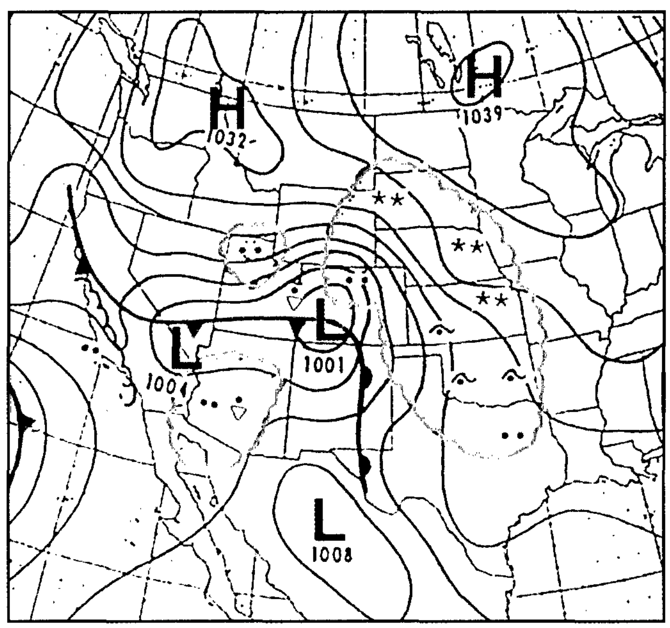

Figure 2-26. Surface, 0000Z/30 January 1980
Seven days later from Figure 2-24 (left). Storm system organizing over the central Rockies as zonal flow short wave approaches.

Polar Jet Stream Systems

The location, configuration and velocity of jet streams and their associated maximum wind bands in the middle and upper troposphere are vital keys in the development of storm systems and severe convective storms. Jet streams meander meridionally in wave motions: names such as "polar jet" and "subtropical jet" have been given to these strong middle and upper-level wind zones. These zones are constantly forming, dissipating, intensifying, weakening, merging and shifting latitudinally and longitudinally. Several jet streams often appear simultaneously on upper air analyses and will be shown in Figures 2-29a through 29c. As mentioned earlier, the polar jet shifts southward beginning in autumn and lies in its winter position over the CONUS. By mid-winter, the main polar jet appears often across the southern CONUS. Figures 2-27 and 2-28 illustrate two typical polar jet stream patterns over the CONUS.

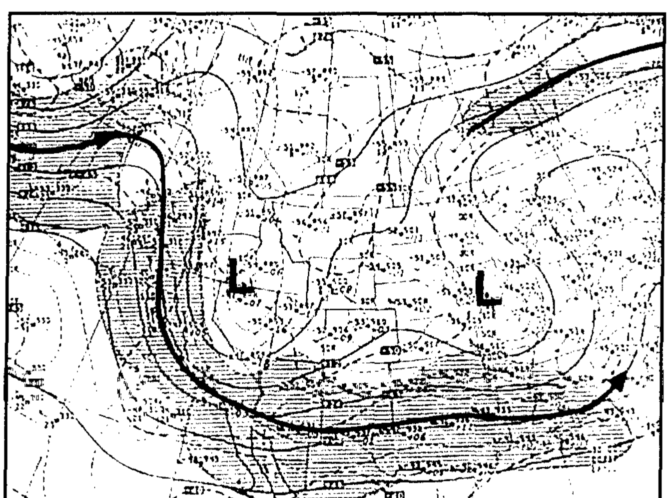

Figure 2-27. 300 mb, 0000Z/17 February 1984
Zonal flow jet stream.

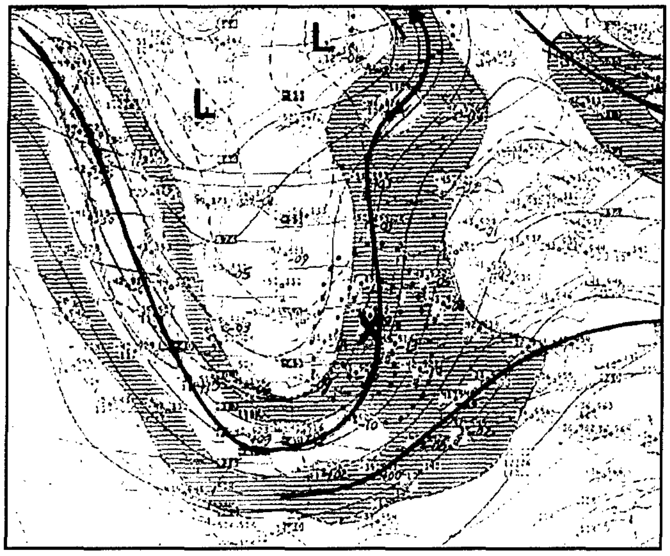

Figure 2-28. 300 mb, 1200Z/26 November 1988
Meridional flow jet stream. The **X** marks the approximate height falls center.

Northern and Southern Branches

Several polar jet streams will often appear on upper air analyses such as shown in Figures 2-27 and 2-28. The warmer southern jet stream is generally associated with frontal cyclogenesis and accompanying heat, moisture and precipitation. Also, the southern jet stream generally has more extensive bands of cirrus and cirrostratus and higher tops than the northern jet stream system. Developing southern Rocky Mountain and Great Plains storm systems are often associated with the southern jet. The colder northern jet stream shown in Figures 2-27 and 2-28 across the northern CONUS has less moisture available within the middle and upper troposphere for significant low development but provides the necessary cold air for major storm development on the southern stream (Figure 2-29a). With a deepening upper trough (increasing amplitude) initial cyclogenesis and extensive baroclinic zone cloudiness are associated with the southern jet. As a reminder, forecasters

should pay attention to the associated jet stream speed maxima as noted by the slim arrows over southern California and the Pacific Northwest area as shown in Figure 2-29b. Major storm and severe thunderstorm events are associated with these speed maxima. Jet steams often split into branches that may make it more difficult to identify these systems on satellite images.

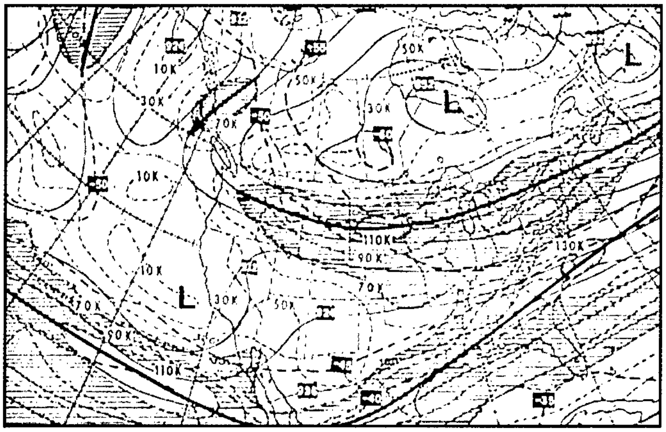

Figure 2-29a. Typical 300 mb, 0000Z/ 14 February 1980
Northern and Southern jet stream branches.

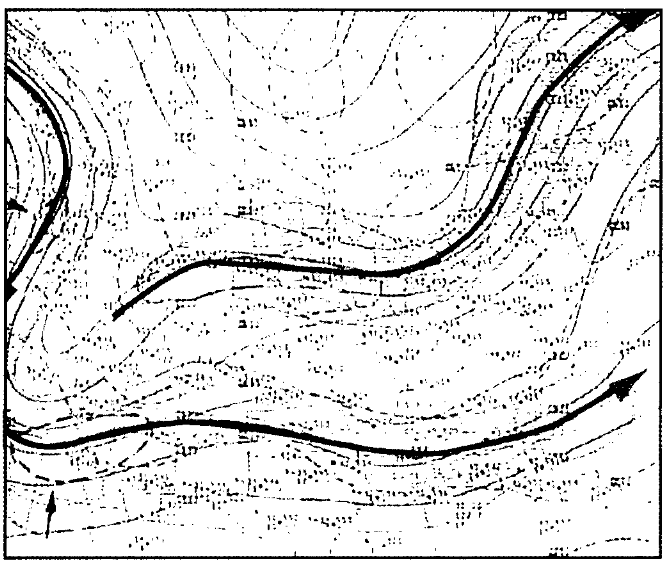

Figure 2-29b. Typical 300 mb, Late February
Northern and Southern jet stream branches.

The northern jet becomes aligned north-south within the colder northwesterly flow on the trough's backside and advects in the necessary cold air, speed maxim and perhaps secondary short waves, to enhance cyclogenesis as shown in Figures 2-29c and 2-30. In Figure 2-29c, a wind maximum of 150 knots appears within the southern branch over the southern Great Plains. The northern branch of the polar jet (110 knot speed max), is driving southward across the western CONUS to support the central CONUS storm system. A major freezing rain and snow event occurred with this developing system. These jet stream systems may split into smaller branches especially with split flow short waves. Figure 2-30 illustrates an example of the jet streams associated with a long wave trough. The long wave is aligned northeast to southwest across the central and southwestern CONUS. The southern branch stretches across the southern and eastern CONUS. Southern storm systems develop within the moist baroclinic zone of the southern jet stream. The northern branch shown over the western CONUS is aligned north to south on the western side of the long wave trough and advects cold air southward. Another segment of the northern polar branch is shown over eastern Canada.

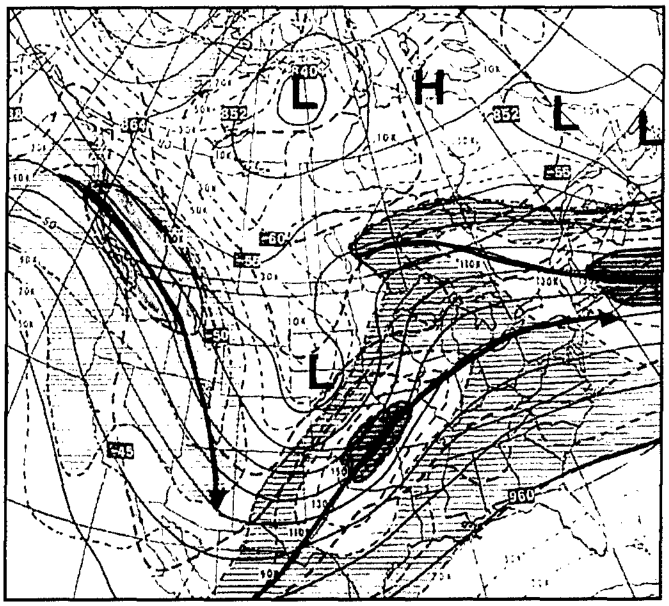

Figure 2-29c. Typical 300 mb, Late January
Deepening trough. Southern and Northern polar jet stream branches.

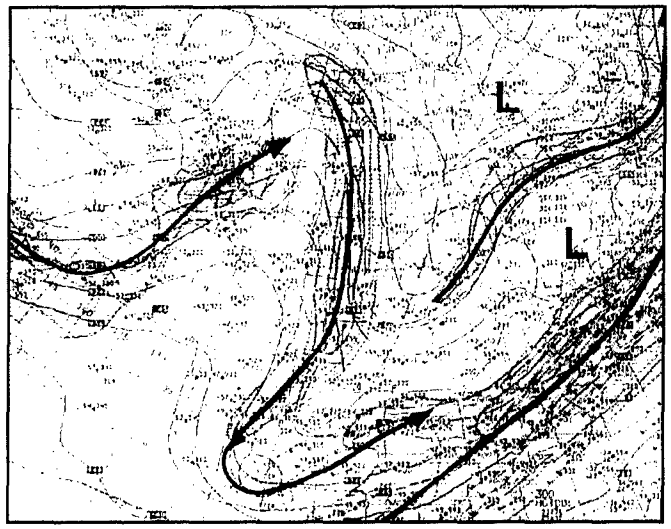

Figure 2-30. 300 mb, 0000Z/1 February 2001
Long wave located over the central and southwestern CONUS. Northern and southern polar jet stream branches.

Figure 2-31 depicts several branches of the polar jet and also the subtropical jet associated with a central CONUS long wave trough.

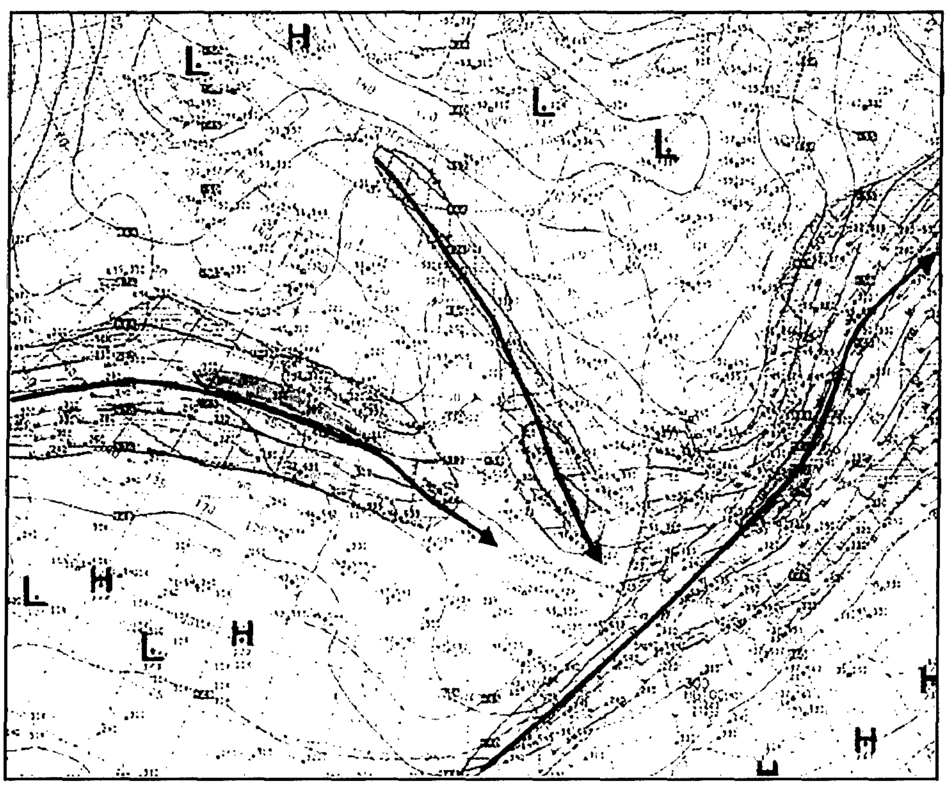

Figure 2-31. 300 mb, 0000Z/3 February 2001
Three branches of the polar jet can be seen in the figure.

Figures 2-32 and 2-33 depict GOES-W and GOES-E IR images at approximately the same time as the 300 mb chart shown in Figure 2-31. Three distinct cloud systems are noticeable. In Figure 2-33, the cloud system over the southern CONUS is associated with the southern branch of the polar jet and the subtropical jet. In Figure 2-32, the cloud system entering the West Coast is associated with a second branch. The north to south cloud system over the northern Great Plains is associated with the northern jet polar branch

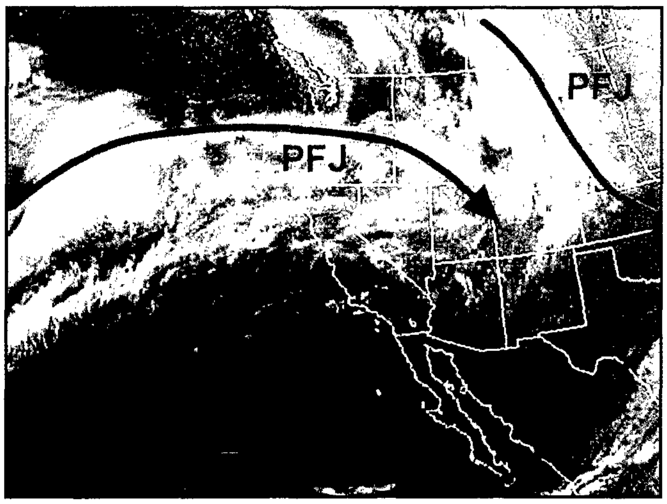

Figure 2-32. GOES-W IR, 0000Z/ 3 February 2001

Figure 2-33. GOES-E IR, 0015Z/ 3 February 2001

Subtropical Jet (STJ)

The subtropical jet (STJ) is the dominant jet stream system across the southern and central CONUS during the summer regime. During the cold season, the subtropical jet migrates southward (south of 25° N) as the polar jet becomes the prevailing jet stream system. During winter the subtropical jet will shift northward ahead of low-latitude Arizona and New Mexico short wave systems that are lifting northeastward over the central CONUS. The satellite image shown in Figure 2-34 depicts a well-defined STJ that has moved northeastward into the southwestern CONUS. The STJ brings warm, moist tropical air with it. Figure 2-35 depicts a water vapor image several hours prior to the photo shown in Figure 2-34.

Figure 2-34. GOES-W IR, 2300Z/ 17 February 2001

Subtropical jet has lifted northeastward into the southwestern CONUS.

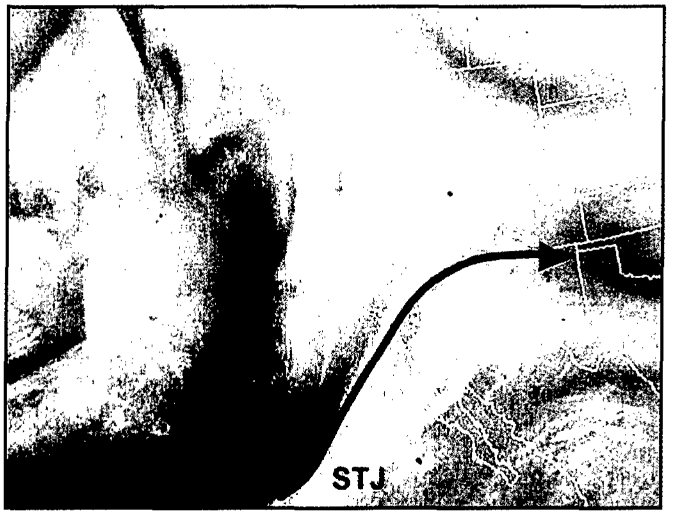

Figure 2-35. GOES-W Water Vapor, 2030Z/ 17 February 2001

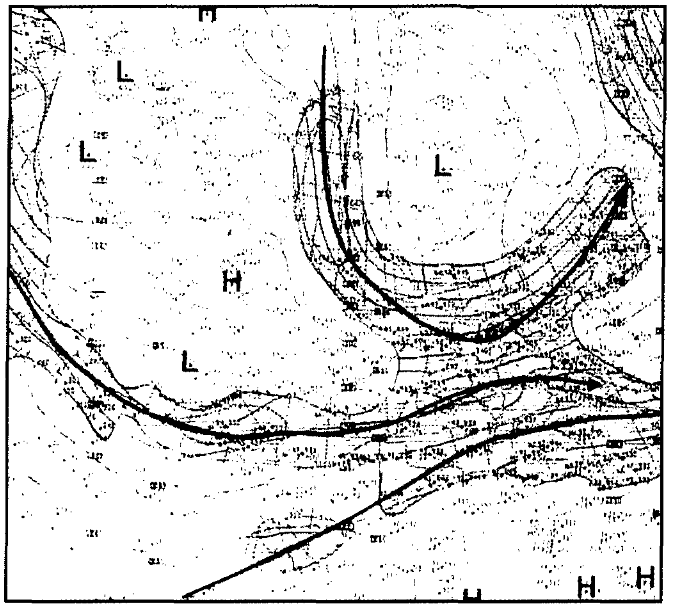

Figure 2-37. 300 mb, 0000Z/20 February 2001

Figures 2-36 through 2-39 depict an event. Figures 2-36 and 2-37 respectively show the 500 mb and 300 mb analyses. In the 300 mb analysis (Figure 2-37), the STJ lies across Mexico and Texas, and the jet is evident in the water vapor images shown in Figures 2-38 and 2-39.

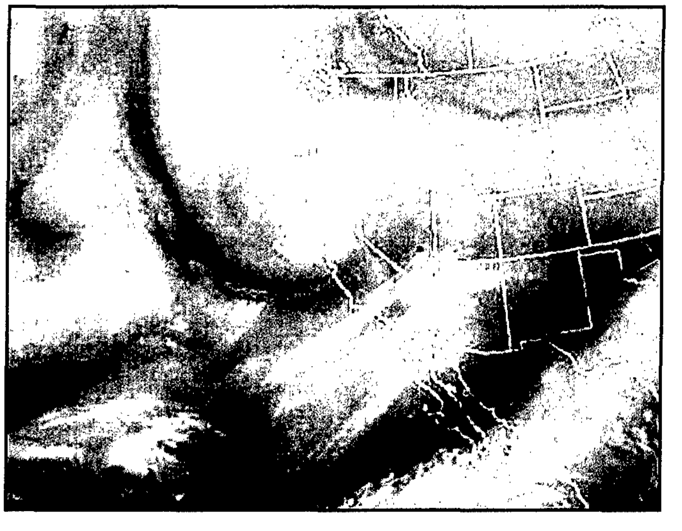

Figure 2-38. GOES-W Water Vapor, 0030Z/ 20 February 2001

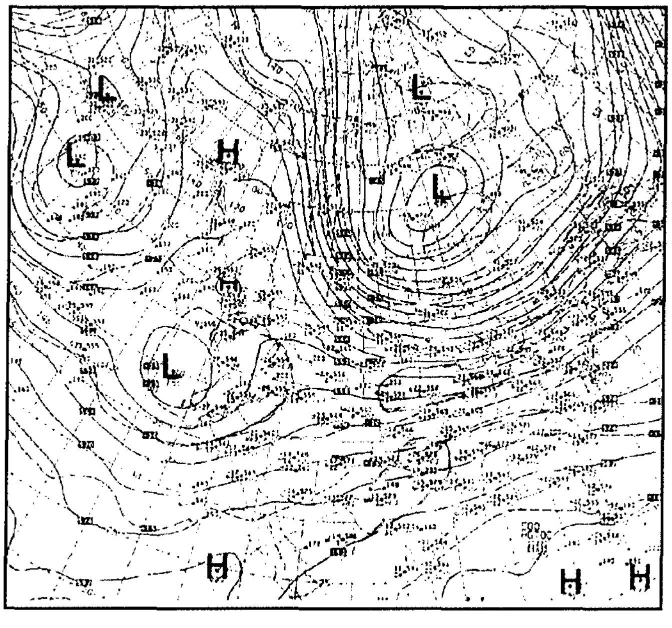

Figure 2-36. 500 mb, 0000Z/20 February 2001

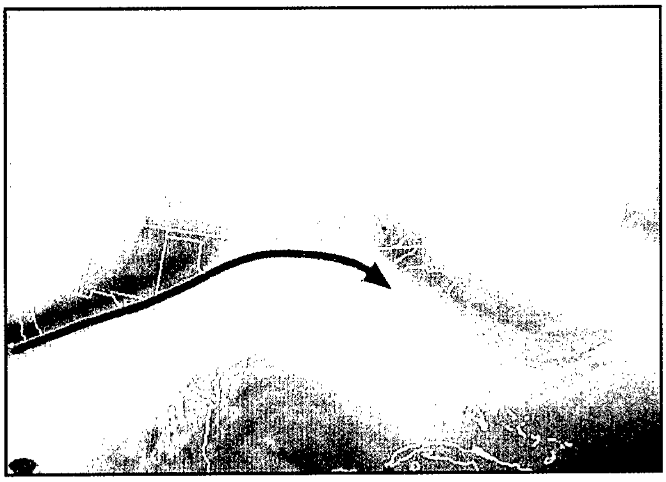

Figure 2-39. GOES-E Water Vapor, 0015Z/ 20 February 2001

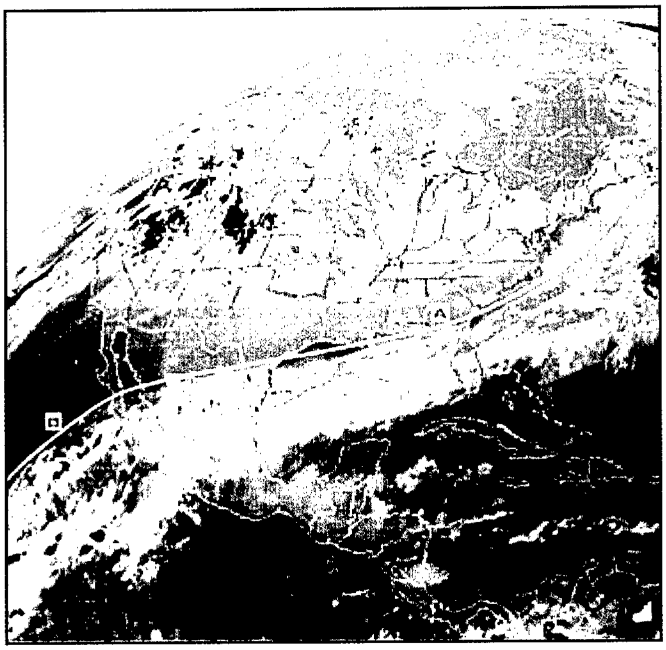

Figure 2-40. GOES-E Enhanced IR, 1130Z/ 25 December 1981
Subtropical jet extends from southern Texas to the Pacific Ocean (B). Lower level southern polar jet is noted by "A" from Texas to Nova Scotia. Northern branch shown over the Great Plains and western CONUS.

During winter, when a major trough regime prevails, the southern polar jet stream will push deep into the southern latitudes. The subtropical jet and the southern polar jet will appear to have merged and become one long, continuous jet stream system; this is shown in Figure 2-40 by an extensive cirrus band from Nova Scotia to the eastern Pacific Ocean area. The segment from Texas extending northeastward (A) is the polar jet (at a lower level); the subtropical jet (higher level) is noted from Texas extending southwestward (B). The subtropical jet segment can be identified by higher cloud tops (in the IR) and anticyclonic curvature. The lower polar jet leaf reveals lower tops and cyclonic curvature. The two jet streams will eventually split; the subtropical jet cirrus band will persist while the polar jet stream cirrus will move away, dissipate or move northward ahead of the next approaching disturbance. In Figure 2-40, the northern polar jet stream is shown over the western and central CONUS.

Jet Shadows and Streaks

Shadows that appear on cloud systems in morning visible images will show jet stream locations (noted by arrows) very well in Figures 2-41 and 2-42. The early morning visible image, Figure 2-41, reveals the cyclonically curved jet stream across the Gulf of Mexico, Florida and the Atlantic Ocean. In Figure 2-42 shadows help define the polar jet across the central CONUS ahead of an approaching short wave.

Figure 2-41. GOES-E VIS, 1546Z/ 25 December 1980
Arrows note polar jet shadows.

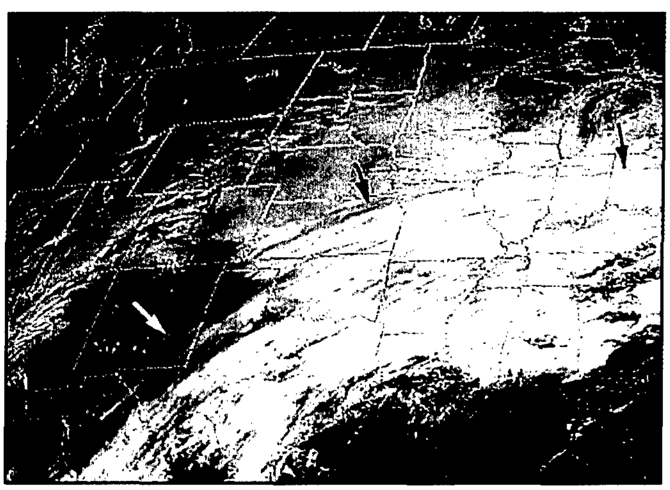

Figure 2-42. GOES-E VIS, 1630Z/ 21 January 1982

Jet stream locations may be identified by cirrus streaks as noted by the arrows in Figures 2-43 and 2-44. In Figure 2-43, cirrus streaks associated with a comma cloud system are visible in the IR image across the Texas Panhandle and southeastern New Mexico area. These baroclinic zone cirrus streaks are lying along and parallel to the jet stream and are also part of the comma cloud tail. The larger arrow notes the subtropical jet (STJ).
In Figure 2-44, the polar jet lies across the southern CONUS; the arrows note visible segments. Cirrus streaks form parallel to the flow and to the right of the jet stream when there is insufficient moisture to form a full cirrus shield. They are usually observed on the backside of troughs. Winds of greater than 60 knots are usually required for their formation.

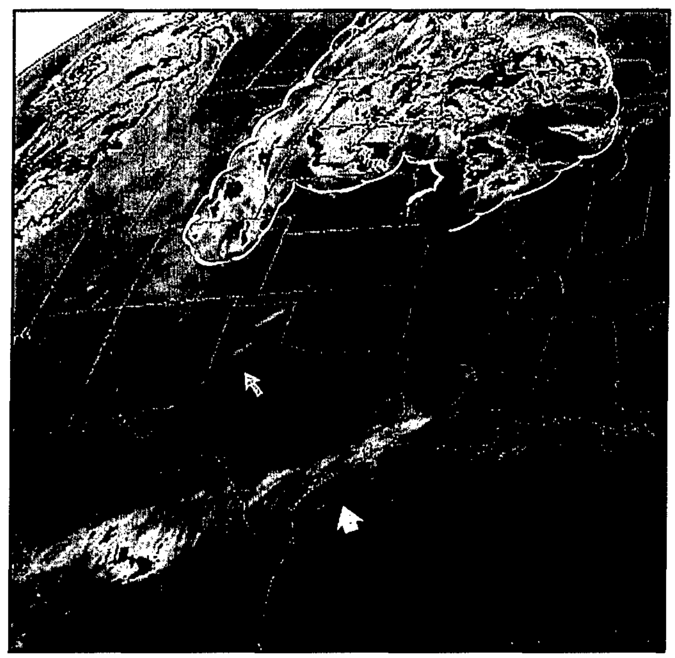

Figure 2-43. GOES-E Enhanced IR, 1330Z/ 31 March 1981
Cirrus streaks help identify jet stream.

Figure 2-44. GOES-E Enhanced IR, 1600Z/ 2 February 1981
Several jet streaks lie across the southern US.

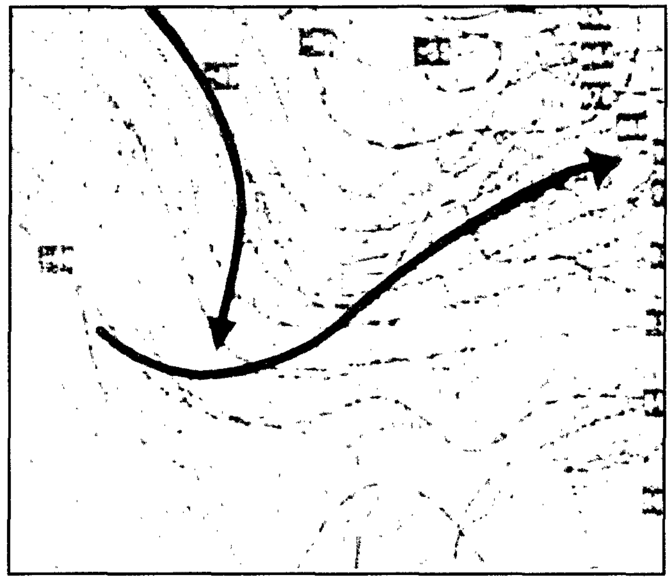

Figure 2-45. 300 mb, 1200Z/5 December 1979

Figures 2-45 through 2-48 illustrate cirrus that forms on the lee side of mountain ranges and are observed from the Rockies to the West Coast. In these cases, high level moisture is present with a well define border along a channeled jet axis (winds parallel to contours), but clouds have not formed. In such cases, cirrus will often form suddenly to the right side of the jet axis as it progresses downstream over a mountain range. A "lee-of-the-mountain" cirrus deck will form downstream from the mountain range and to the right of the jet axis as shown in Figures 2-45 and 2-46. In Figure 2-46, the arrows note cirrus layers. The layer began over the New Mexico and southeastern Colorado Mountains and lies to the right of the jet stream across the central Great Plains.

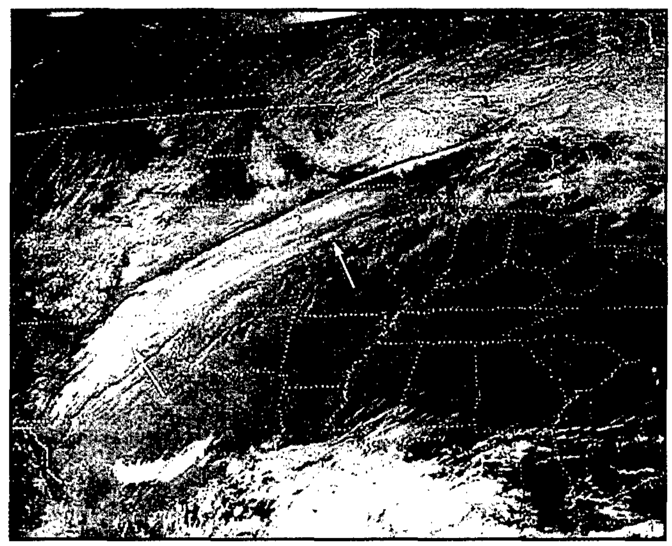

Figure 2-46. GOES-E VIS, 1547Z/ 5 December 1979
Approximately 4 hours later than Figure 2-45.

Figures 2-47 and 2-48 show two more events. In Figure 2-48, the cirrus over Arizona and New Mexico is thin but thickens along and east of the Colorado Rockies (bright white). In IR images, cirrus that forms along mountain ranges could be identified as cumulonimbus tops to the untrained eye.

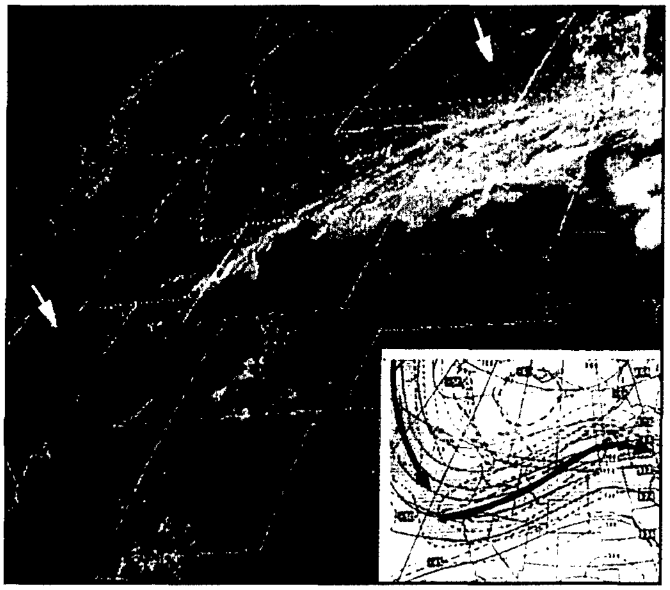

Figure 2-47. GOES-E VIS, 1530Z/ 22 February 1982

Inset 300 mb image from 1200Z/22 February 1982.

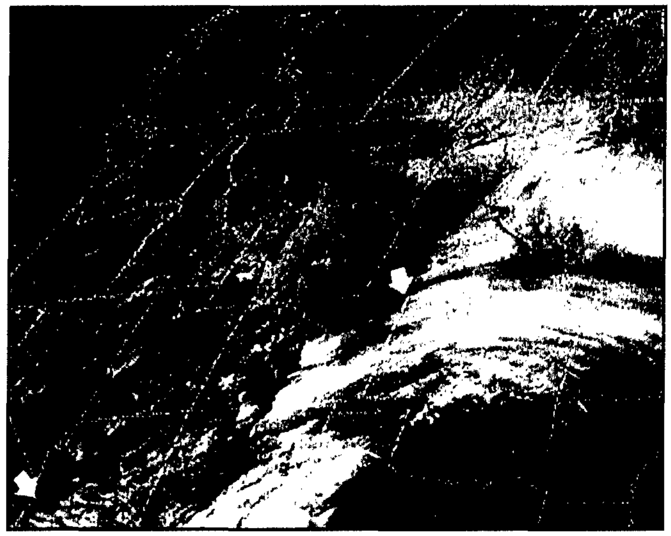

Figure 2-48. GOES-E VIS, 1630Z/ 5 December 1981

Arrows mark cirrus development east of the mountains.

Winter Regimes

Chapter 3

Western Conus

Long Wave Troughs/Ridges

As presented earlier in Chapter 2, General Circulation, ridging often appears along and/or off the West Coast, especially during January and February, when a long wave trough exists east of the Rocky Mountains. Generally, these ridges last for several days or weeks before a strong short wave moves into the area and flattens or shifts the ridge eastward. The alignment and position of this ridge determines the steering of inland storm systems moving southward into the northern CONUS from Canada.

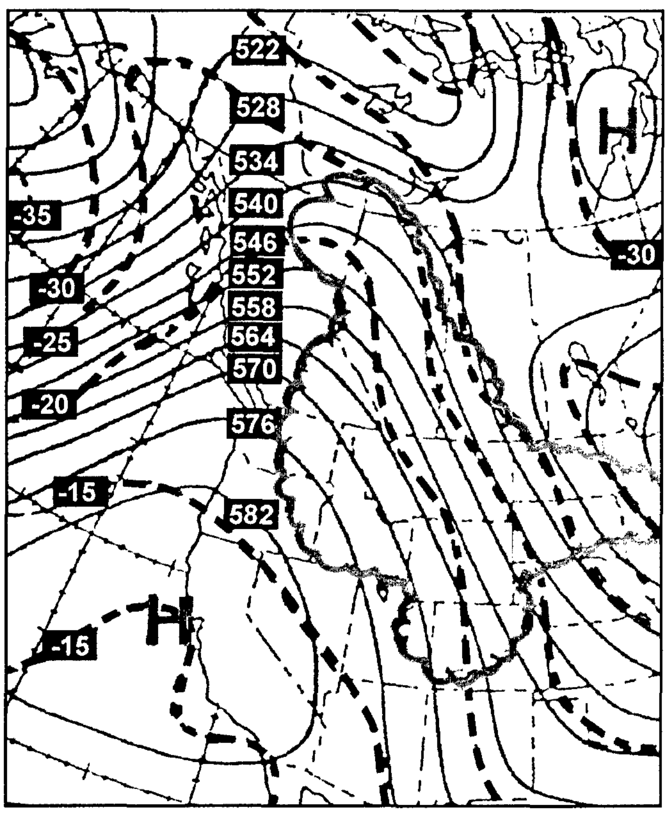

Figure 3-1. 500 mb, 1200Z/17 January 1977
Strong ridge shown over the West Coast.

It should be mentioned that below normal precipitation would affect the western CONUS if the ridge depicted in Figure 3-1 persists for an unusually long period of time. This was the case during the winter season of 1976-1977 when drought conditions extended from the West Coast to the Rockies.

The appearance of ridges over the West Coast typifies a normal winter regime. Occasionally, a persistent cyclonic flow pattern (Aleutian low shifts eastward to Alaska) over the West Coast extends far out into the Pacific Ocean (Figure 3-2). In these cases, continued heavy rains and floods may occur. Two main criteria are a persistence of a long fetch of moist, west to southwest flow in the middle levels and a surface/lower level thermal gradient, i.e., quasi-stationary east-west frontal zone as illustrated in Figure 3-3.

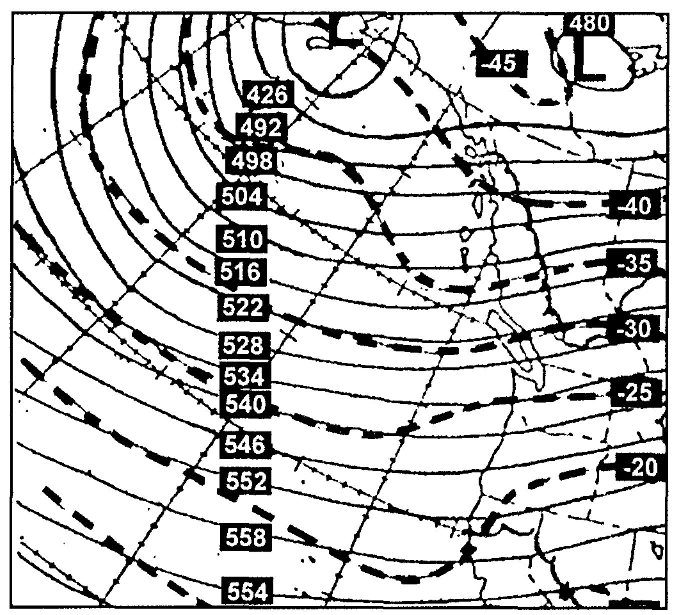

Figure 3-2. 500 mb, 0000Z/14 January 1980
Strong west to east zonal flow. Weak thermal trough offshore supports frontal wave shown in Figure 3-3.

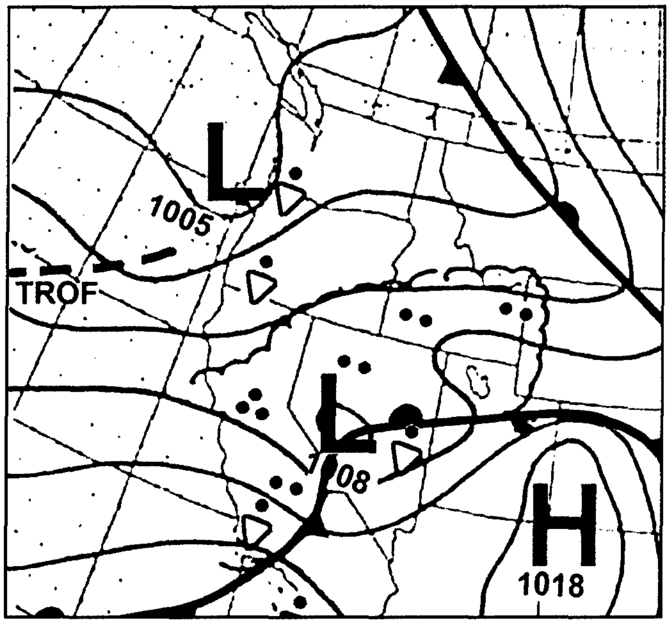

Figure 3-3. Surface, 0000Z/14 January 1980
Frontal wave shown over Nevada. Persistent rainfall. Snow levels above 8,000 ft with heavy mountain snows.

The absence of the long wave ridge over the eastern Pacific and the West Coast of North America brings stormy and wet conditions across the western CONUS. In the following example, Figure 3-4, the long wave ridge has shifted further eastward into west-central Canada and the CONUS; consequently Pacific storms are not blocked as they approach the coastal areas.

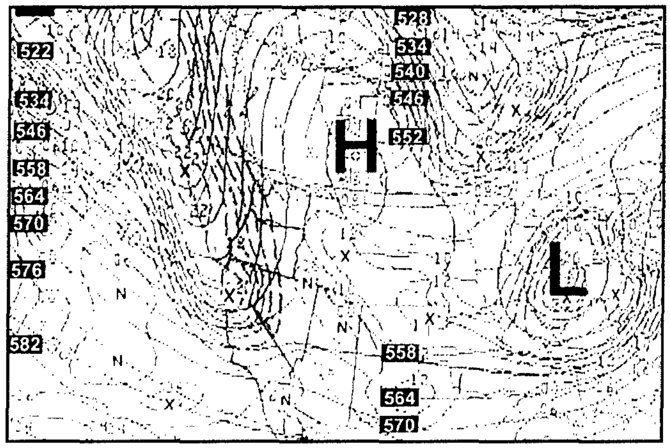

Figure 3-4. 12HR FCST 500 mb HEIGHTS/ VORTICITY, 0000Z/30 January 2000

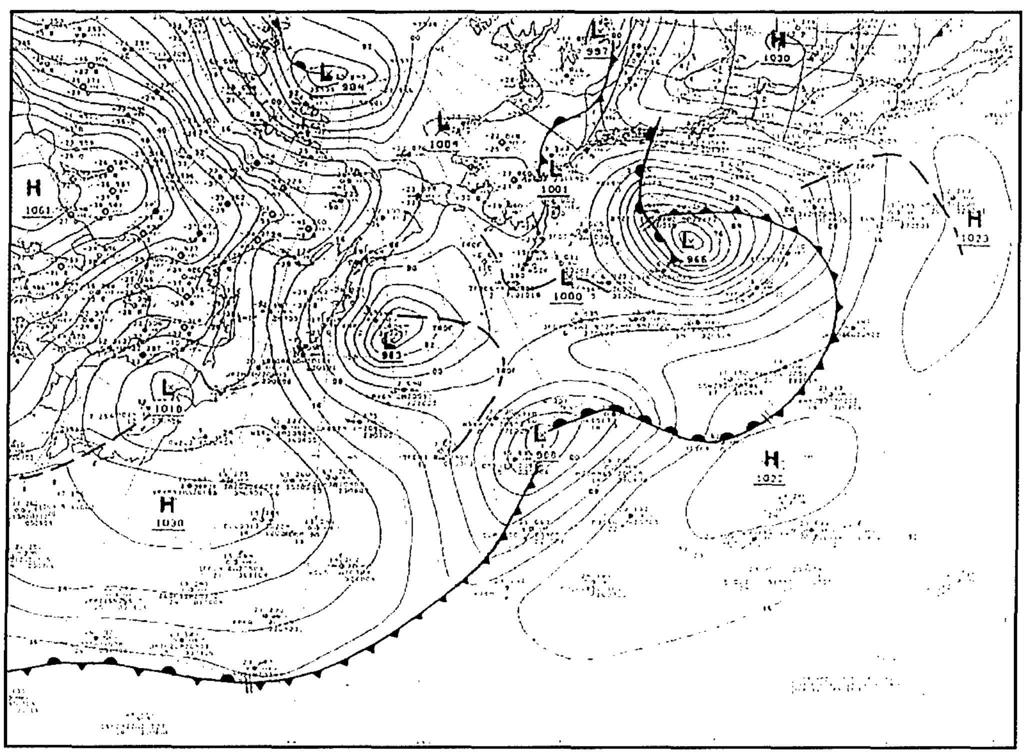

Figure 3-5 depicts the surface conditions across the northern Pacific Ocean. Frontal waves develop over the western Pacific and generally are in the occluded mature stage as they reach the West Coast of North America.

Figure 3-5. Surface, 0000Z/30 January 2000
Low pressure systems tracking eastward across the northern Pacific Ocean.

Eastern Pacific Cyclogenesis

Western CONUS forecasters should be aware that frontal cyclogenesis can develop rapidly over the eastern Pacific as shown in Figures 3-6 and 3-7. Satellite interpretation is a must for West Coast forecasters due to the sparse data over ocean areas and also is very helpful as a check on how the models are handling these developing systems. Figures 3-6 and 3-7 depict a baroclinic leaf pattern that evolved into a comma cloud system off the West Coast of North America. In Figure 3-6, the baroclinic cloud system appears as a fat cloud shield (A). Strong cyclonic curvature, noted by the arrow in Figure 3-6, indicates that the jet stream is punching into the system. Ten hours later, Figure 3-7 a comma cloud system has evolved. This developing storm may affect West Coast locations within 24 hours.

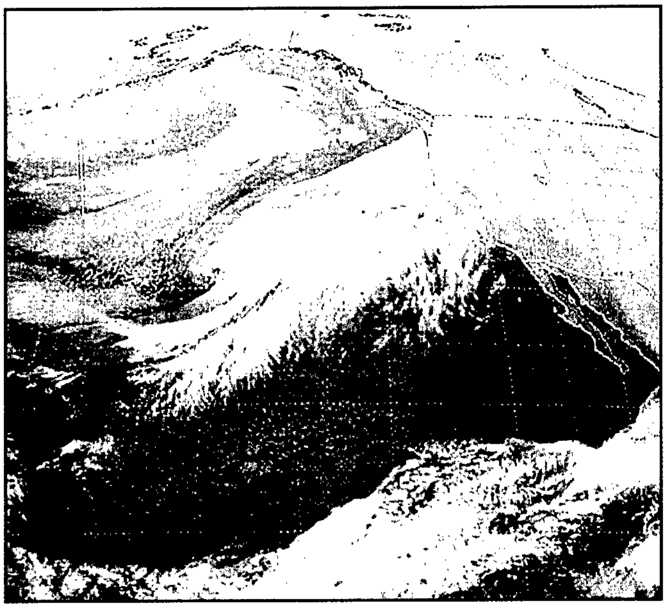

Figure 3-7. GOES-W IR, 0715Z/ 2 December 1979
Ten hours later than Figure 3-6.

Figure 3-6. GOES-W IR, 2115Z/ 1 December 1979

As mentioned earlier, many storm systems are in the occluded stage as they approach the West Coast of North America (Figure 3-8). Wrap-around dry slots are associated with vertically stacked comma systems that have reached the dissipation stage as shown in Figure 3-8. These occluded upper lows generally do not move into western Canada or the CONUS when an upper ridge is in place over the land areas. However, the associated PVA, Pacific moisture and front will continue eastward and weaken in time over the mountainous areas of the western CONUS. Frontal cyclogenesis may occur at the triple point of the occlusion (similar to triple point low formation along the East Coast). In Figure 3-8, the baroclinic frontal zone noted by the black arrow, show signs of waving as a positive vorticity system, (white arrow) approaches. This event was presented to show West Coast forecasters that new storms may develop within old occluded systems in their "own backyard."

Figure 3-8. GOES-W VIS, 1915Z/ 27 February 1980

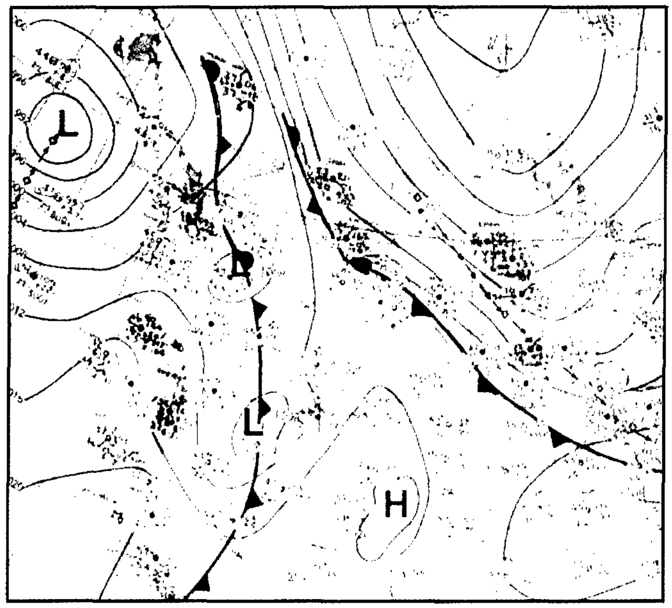

Figure 3-9. Surface, 1200Z/28 February 1980
Maritime cold front has moved into the Great Basin area. Large cP ridge in place over the Great Plains.

Figures 3-9 and 3-10 respectively depict the surface and 500 mb the following morning (1200Z). In the figures, the occluded front and short wave have moved inland. A frontal low is shown over Nevada. Within 24 hours, the mP frontal system "was lost" over the Rocky Mountains, and most likely, lifted over the cP air mass over the Great Plains. The associated short wave merged in with the large cyclonic flow over the central and eastern CONUS.

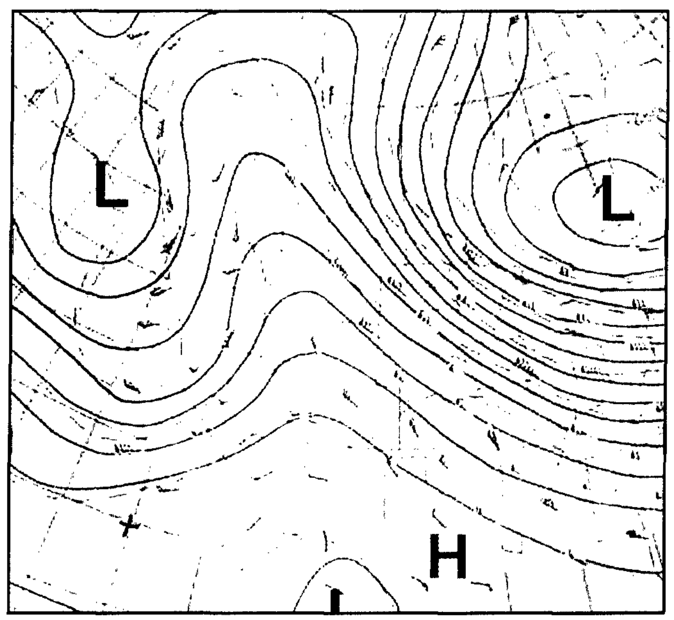

Figure 3-10. 500 mb, 1200Z/28 February 1980
Short wave has entered the West Coast. Associated 500 mb low dissipated within 24 hours.

Long Wave Retrogression

Another regime, which produces significant precipitation along the Pacific Coast and across the southwestern CONUS, is shown in the following three examples:

Occasionally, there is a shift westward of the CONUS long wave trough/ridge regime towards the West Coast and mid-Pacific Ocean (Figure 3-11). Short waves from the Gulf of Alaska and western Canada move south or southwestward instead of southeastward and reflect digging of the polar jet. In many cases, a closed low appears within the base of the trough as shown in Figure 3-12. These actions indicate a westward relocation of the long wave trough. The closed low shown off the California coast in Figure 3-12 may remain stationary for several days or longer. An increase in precipitation over central and southern California occurs with this regime and spreads eastward across the southwestern CONUS. The visible satellite picture, Figure 3-13, reveals a closed low off the northwestern coast of Baja California. Figure 3-14 illustrates another example of a closed low located off the southern California coastal area.

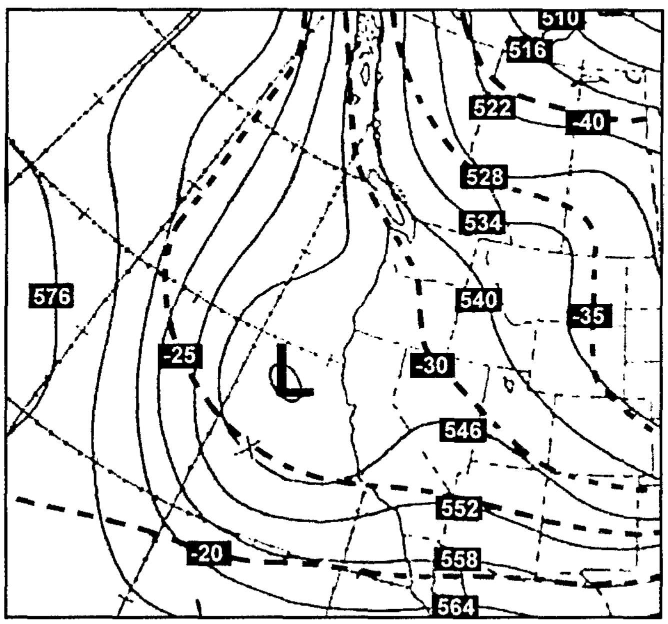

Figure 3-11. 500 mb, 0000Z/31 January 1979
Low has developed within the base of long wave.

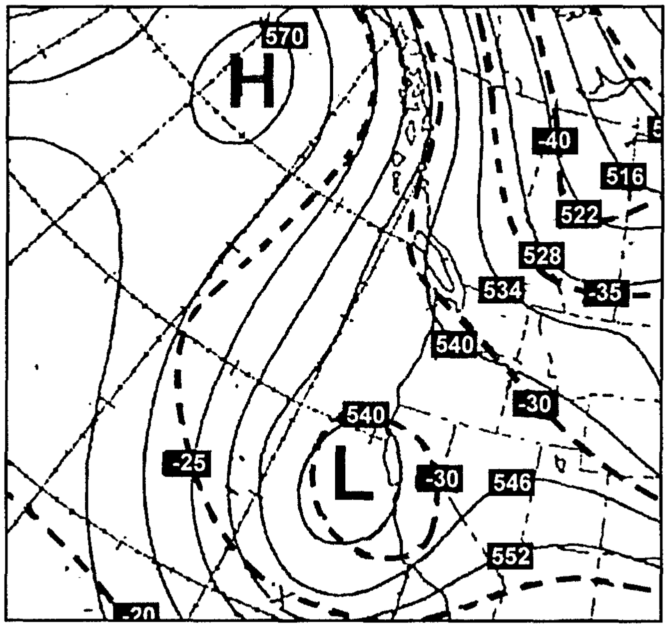

Figure 3-12. 500 mb, 1200Z/31 January 1979
Low approaching central California coast.

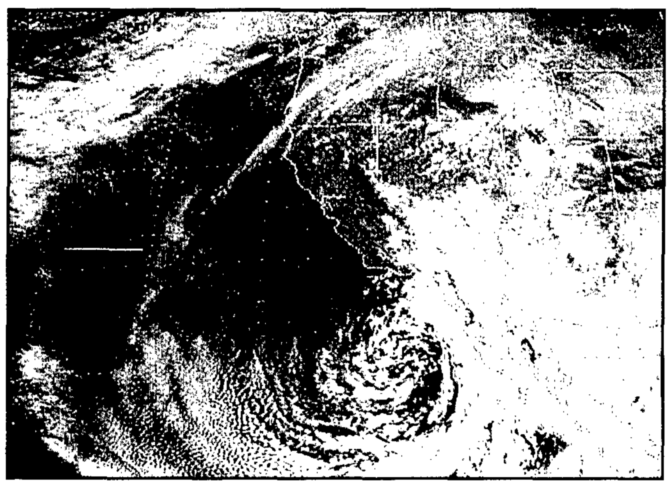

Figure 3-13. GOES-W VIS, 8 December 1982
Upper low shown off the Baja California coast.

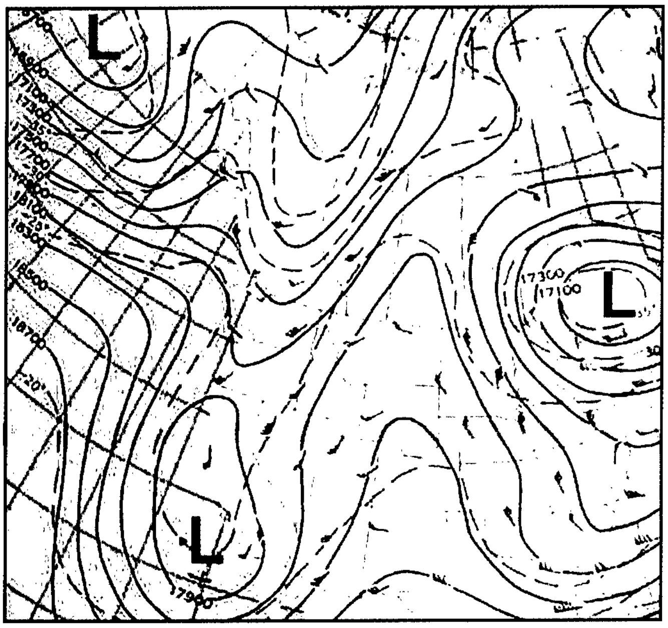

Figure 3-14. 500 mb, 1200Z/5 March 1981
Not related to Figure 3-13.

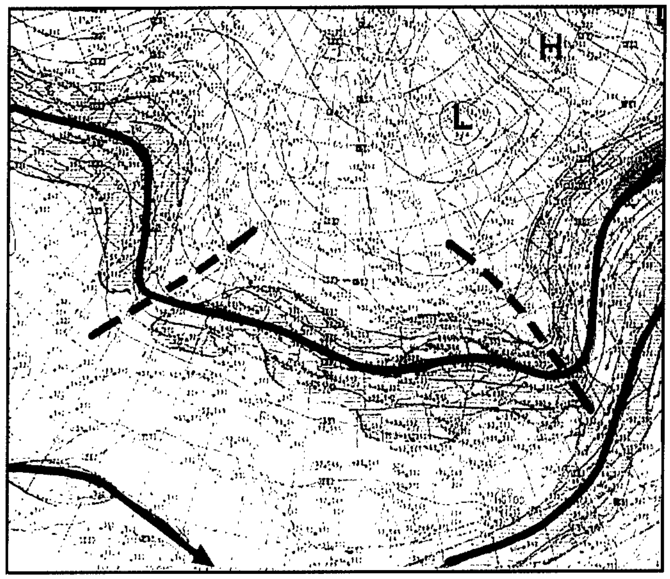

Figure 3-15. 250 mb, 0000Z/6 February 2001
Short waves moving through the long wave. Polar jet lies across the CONUS.

Figures 3-15 through 3-27 depict the shifting long wave trough from the central CONUS to the West Coast region over an eight-day period. In this example, a north to south long wave trough was located over the central CONUS for over a month creating a persistent winter mixed of precipitation as short waves moved through the long wave. Freezing precipitation events occurred often across the central CONUS. The following sequence shows the relocation of the long wave to the West Coast over a eight-day period. A series of Gulf of Alaska short waves dug southward off the West Coast of North America as the long wave shifted westward. At the start of this sequence, the long wave trough was not noticeable over the central CONUS as shown in Figure 3-15; short waves were transiting through the long wave trough. Figures 3-16 and 3-17 respectively depict the IR and water vapor images for the same time as Figure 3-15.

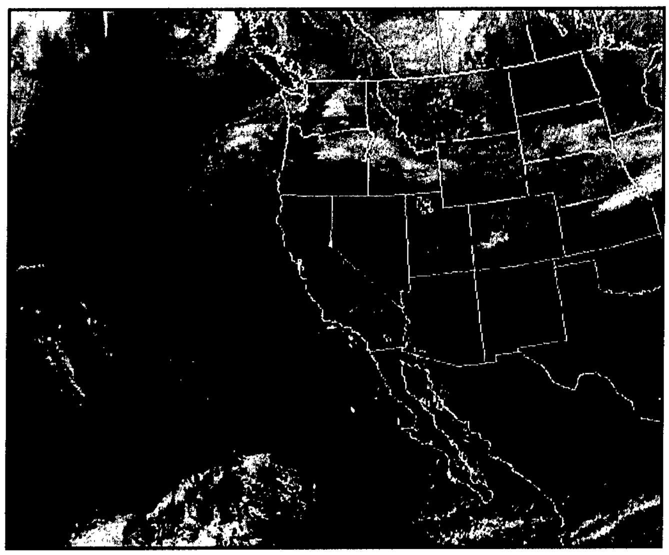

Figure 3-16. GOES-W IR, 0000Z/ 6 February 2001

Figure 3-17. GOES-W Water Vapor, 0000Z/ 6 February 2001
Pacific short wave is noticeable west of Oregon.

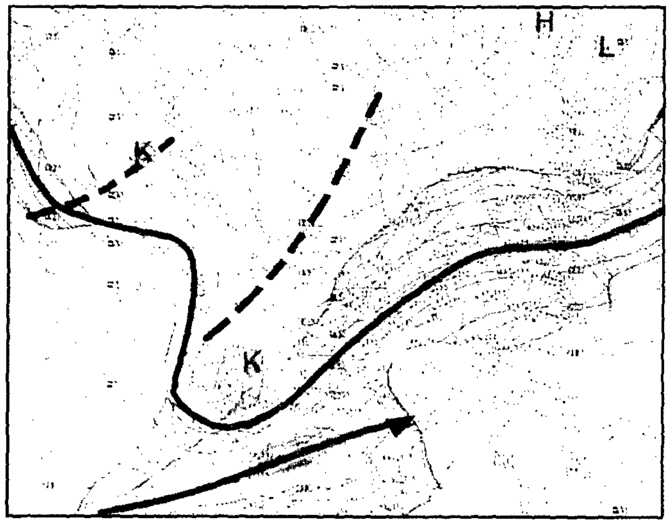

Figure 3-18. 200 mb, 1200Z/8 February 2001

Figures 3-18 through 3-20 depict the changing upper-air pattern 60 hours later. The short wave shown off the Pacific Northwest coast in Figure 3-15 has dug southeastward into the southwestern CONUS as shown in Figure 3-18. The jet stream configuration has changed from west-northwest to east-southeast to a southwest to northeast flow during this 60-hr period. Another Gulf of Alaska short wave can be seen in the upper left of the illustration that will become a "major player" in the long wave westward relocation. Figures 3-19 and 3-20 respectively depict the infrared and water vapor images for the valid time of Figure 3-18. A pronounced cyclonic circulation can be seen in both images associated with the next storm system.

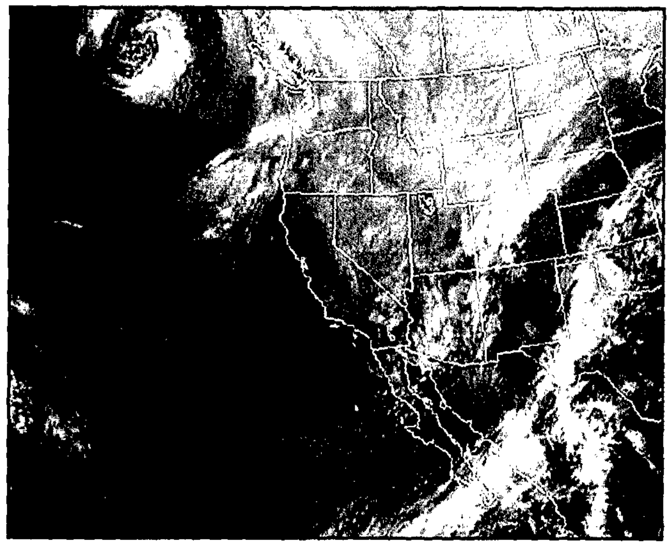

Figure 3-19. GOES-W IR, 1200Z/ 8 February 2001

Figure 3-20. GOES-W Water Vapor, 1200Z/ 8 February 2001

The southwestern storm system shown in Figure 3-18 has moved northeastward across the Great Plains during the next three days (Figure 3-21). In Figure 3-21, the second Gulf of Alaska short wave has dug southward off the West Coast with a low shown along the Washington coast. Figures 3-22 and 3-23 respectively show the infrared and water vapor images for the same valid time.

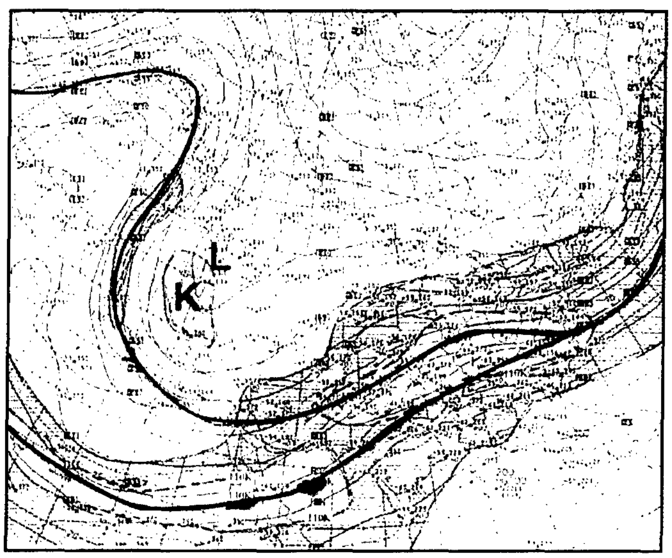

Figure 3-21. 200 mb, 1200Z/11 February 2001

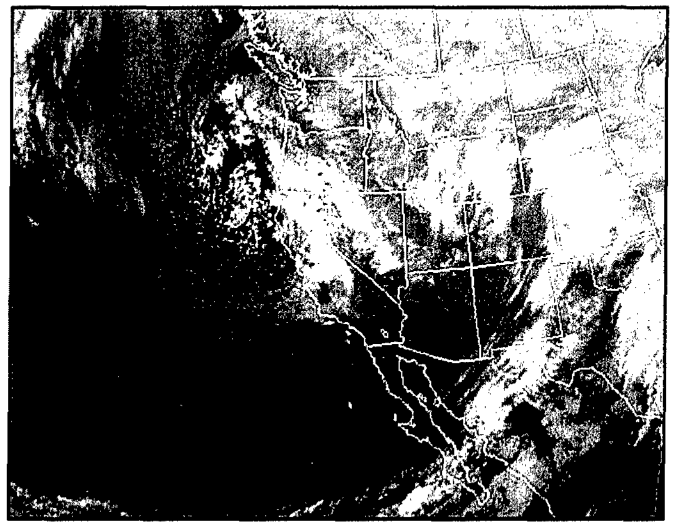

Figure 3-22. GOES-W IR, 1200Z/ 11 February 2001

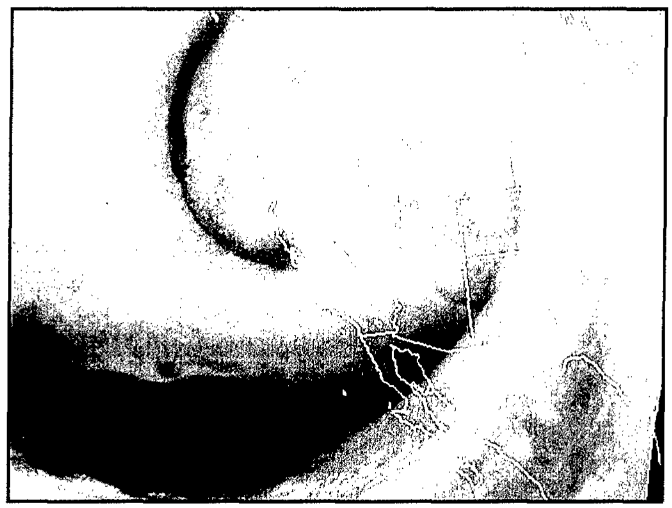

Figure 3-23. GOES-W Water Vapor, 1200Z/ 11 February 2001

Finally, in Figure 3-24 (60 hours later) a southwest to northeast oriented long wave trough appears over the western CONUS. The short wave has dug further southward into the southwestern CONUS as shown in the 500 mb analysis (Figure 3-25). This long wave regime occurs at least once during the winter season. The low system at base of the long wave may "sit there" for several days until another strong short wave approaching from the northwest forces the low to kick out of the long wave's base. Figures 3-26 and 3-27 respectively show the infrared and water vapor images.

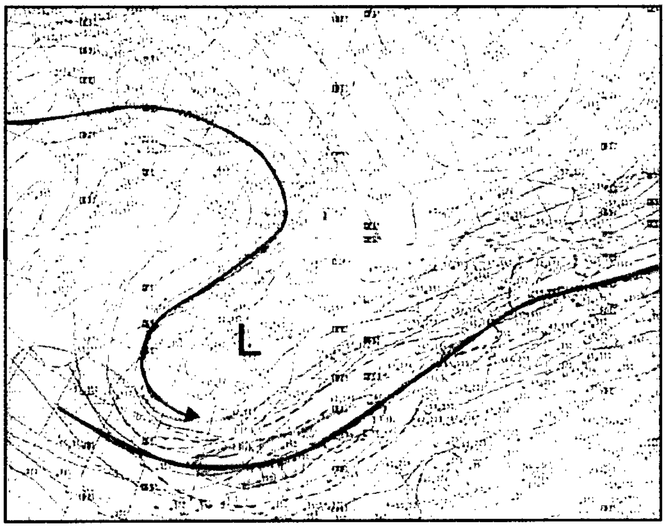

Figure 3-24. 200 mb, 0000Z/14 February 2001

Figure 3-26. GOES-W IR, 0000Z/ 14 February 2001

Cold air cumulus within the cyclonic flow noted by the arrow.

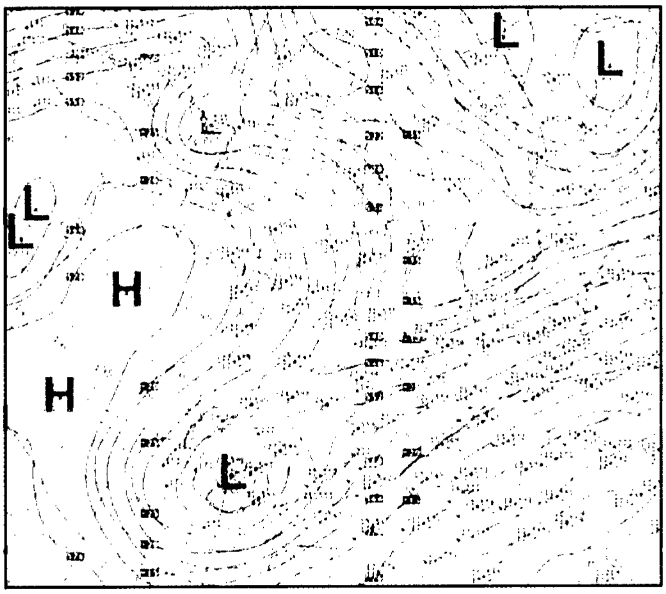

Figure 3-25. 500 mb, 0000Z/14 February 2001

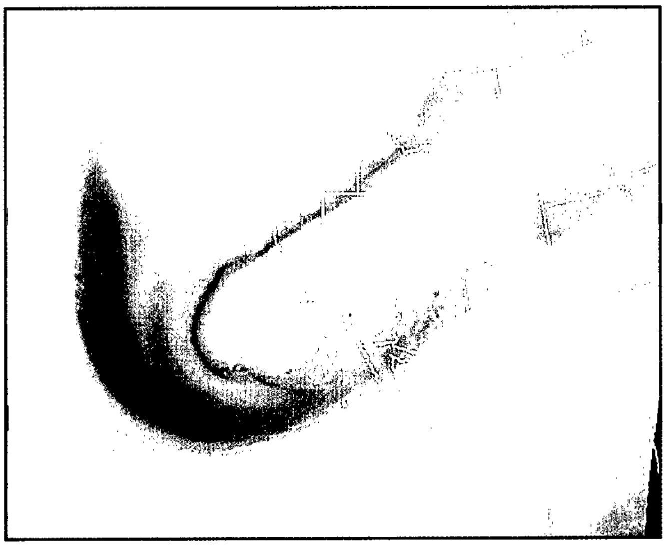

Figure 3-27. GOES-W Water Vapor, 0000Z/14 February 2001

Storm systems continue to drop southward along the Pacific Coast. Some areas in southern California receive their highest monthly rainfall of the year during February (Figures 3-28 through 3-30). In Figure 3-28, notice how far south the short wave is within the stronger westerlies. A strong blocking high is positioned over Alaska which force storm systems southward. This regime can produce disastrous results for the southwest CONUS if the regime lasts for several days. A series of moist short waves will trigger heavy orographic rains over southern California that will produce floods and mudslides. Figures 3-29 and 3-30 respectively depict the associated surface conditions and cloud cover later in the afternoon.

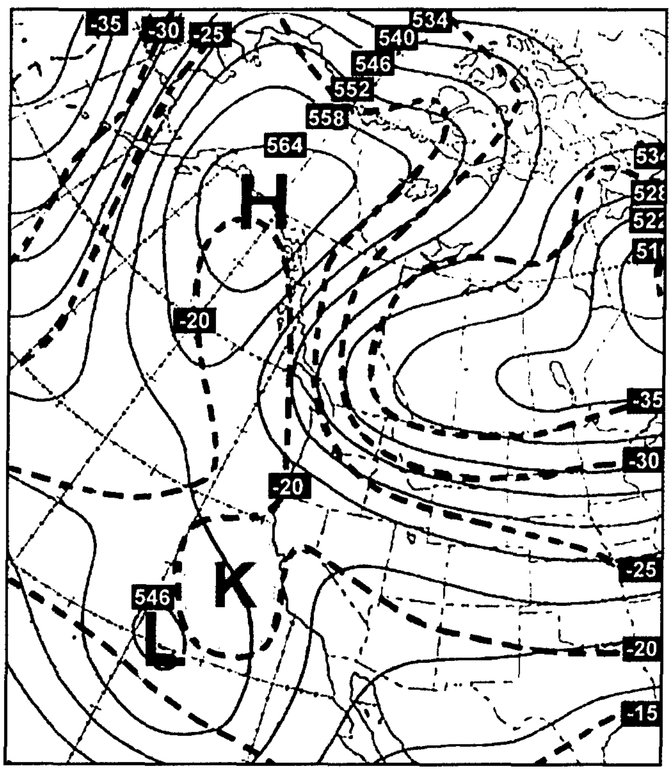

Figure 3-28. 500 mb, 1200Z/13 February 1980

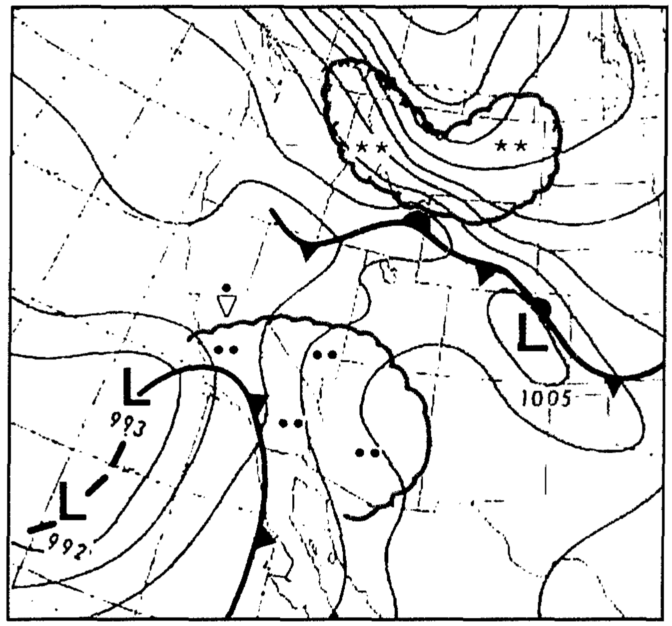

Figure 3-29. Surface, 2100Z/13 February 1980

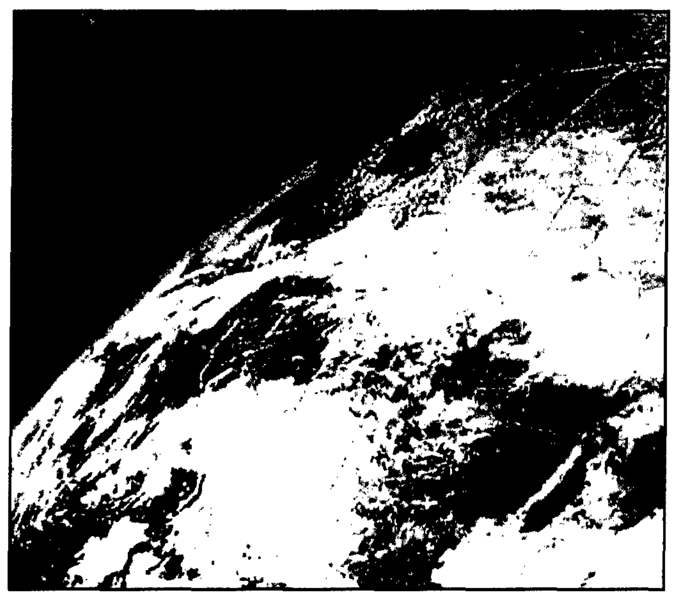

Figure 3-30. GOES-E VIS, 2118Z/ 13 February 1980

December marks the beginning of the winter precipitation season in Arizona and New Mexico. Precipitation shows a marked increase over November (50-100% increases) with monthly amounts reaching two inches or more in the higher mountains. Heavy snowfall over central and northern Arizona, southern Nevada and Utah eastward to Colorado and New Mexico are associated with slow-moving closed lows within the mid and upper levels (Figure 3-31).

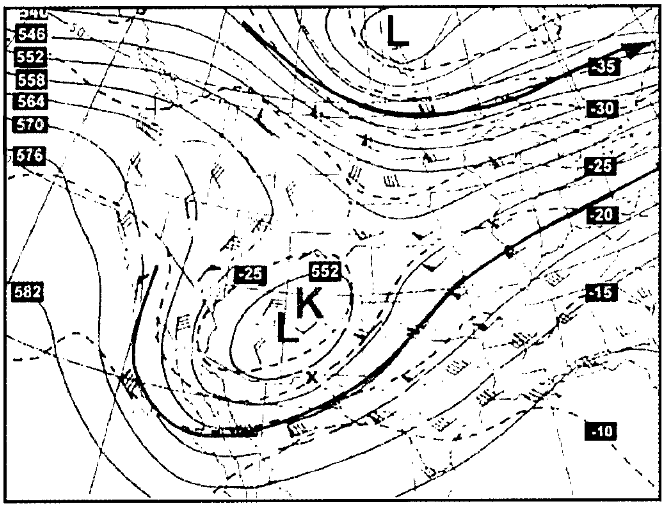

Figure 3-31. Typical 500 mb Low, 0000Z/ 30 January 1982

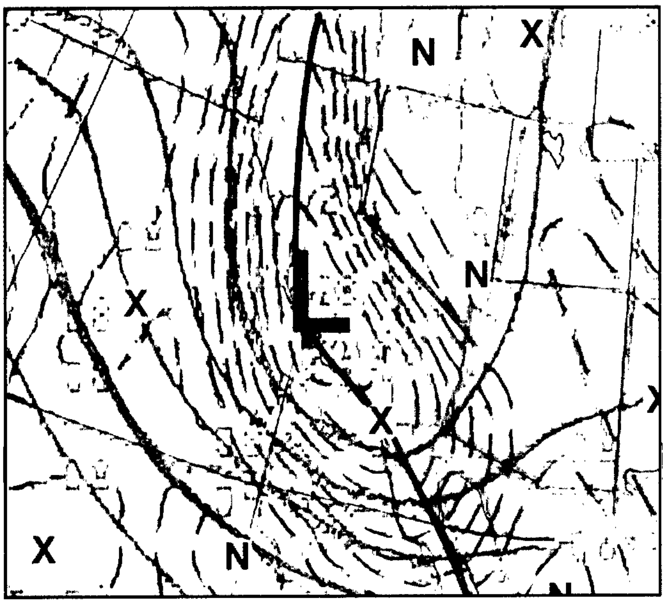

Figure 3-32. 500 mb HEIGHTS/VORTICITY, 1200Z/20 February 1998

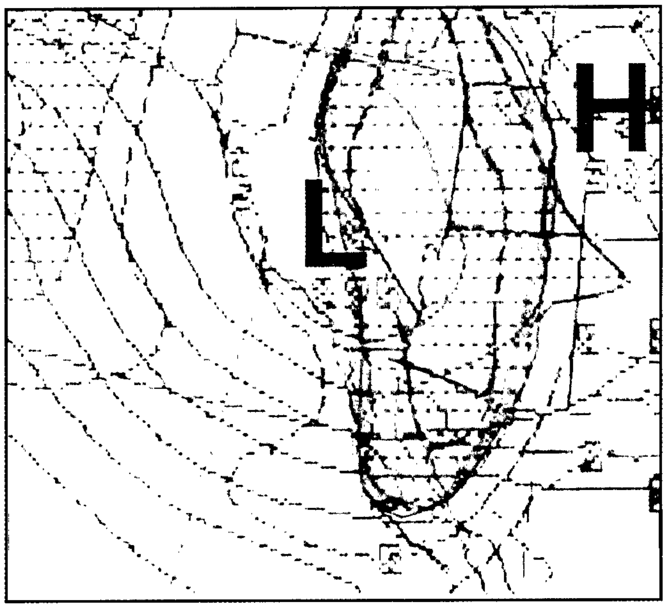

Figure 3-33. 700 mb HEIGHT/REL HUMIDITY, 1200Z/20 February 1998

An example is shown in Figures 3-32 through 3-36 (not related to Figure 3-31). Figure 3- 32 depicts a developing low within an upper trough over central California. The accompanied Pacific moisture (> 70% RH) is shown in Figure 3- 33. The 12-hour forecast, Figures 3-34 through 3-36, shows that the upper low will move into southern Arizona. The east-west vorticity isopleths (deformation zone; noted by the arrow) shown over central and northern Arizona in Figure 3-34 and the associated moisture depicted in Figure 3-35 typifies a heavy snowfall regime over northern and central Arizona and New Mexico. The forecast surface and thickness are shown in Figure 3-36. A closed 540 cold pocket is noted by the "K". The surface pressure gradient is often weak with these southwest CONUS storms, however, surface winds can be strong (the 700 mb level is often used to determine if strong winds will occur). Low top thunderstorms may appear within the cold pocket especially during the heating hours.

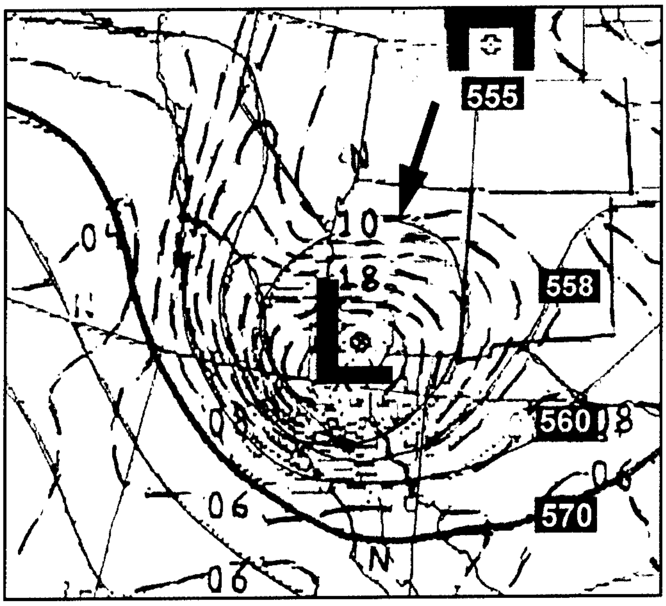

Figure 3-34. 24HR 500 mb HEIGHTS/VORTICITY, 0000Z/21 February 1998

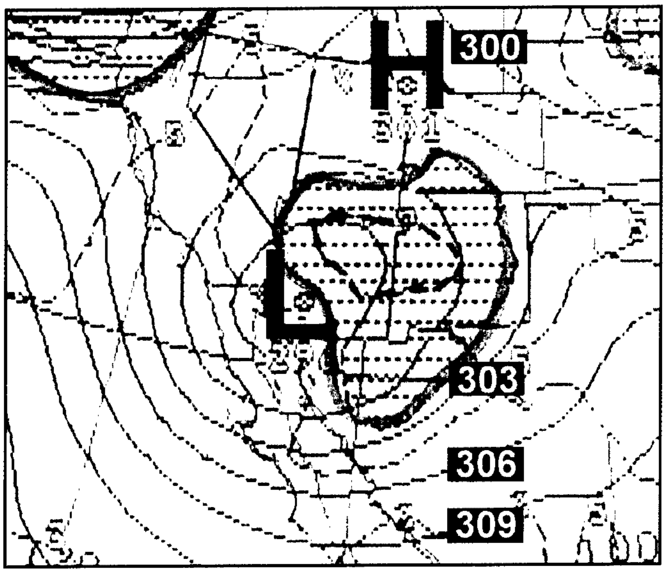

Figure 3-35. 24HR 700 mb HEIGHT/REL HUMIDITY, 0000Z/21 February 1998

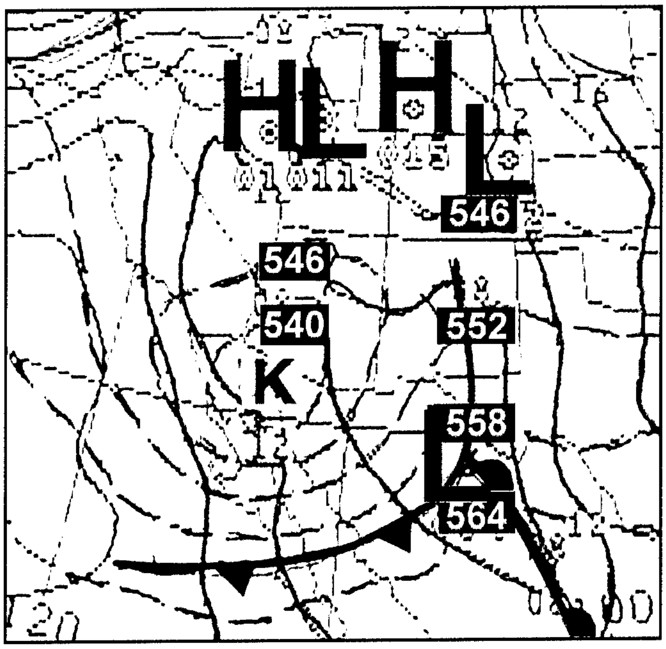

Figure 3-36. 24HR MSL PRES/1000-500 mb THKNS, 0000Z/21 February 1998

Zonal Flow

So far, examples of long wave trough and ridge regimes and movement of short waves through these long wave features have been presented. Short waves moving through zonal flow occur often across the CONUS throughout most the year. Occasionally, a short wave moving across the western CONUS may deepen rapidly and take on the appearance of a long wave feature. A short wave may enhance the new position of a long wave trough. A shift of the hemispheric long wave troughs and ridges, east or west occurs throughout the winter season. Examples of long wave ridges, which block Pacific storms over the western CONUS, were presented earlier. Conversely, zonal flow regimes will occur more often throughout the winter. Many Pacific troughs move across the CONUS. Significant snowfall and perhaps strong cold air advection winds are likely over the central and northern areas of the western CONUS. Forecasters over the Great Plains should keep a suspicious eye on deepening Pacific troughs especially when models forecast continued deepening and upper low development. When these systems move out of the mountains into the Great Plains and interact with Gulf moisture tongues and Canadian air masses then significant winter storms may evolve. Figures 3-37 and 3-38 exemplify trough deepening over the western CONUS.

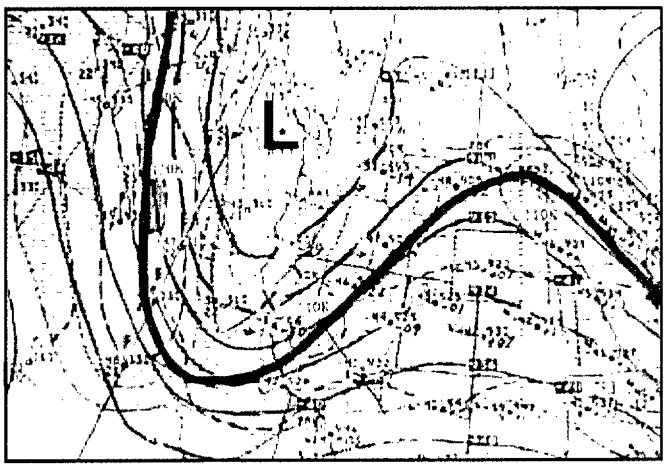

Figure 3-37. 300 mb, 0000Z/25 November 1983
Digging trough shown off the West Coast Several jet maxima associated with the system.

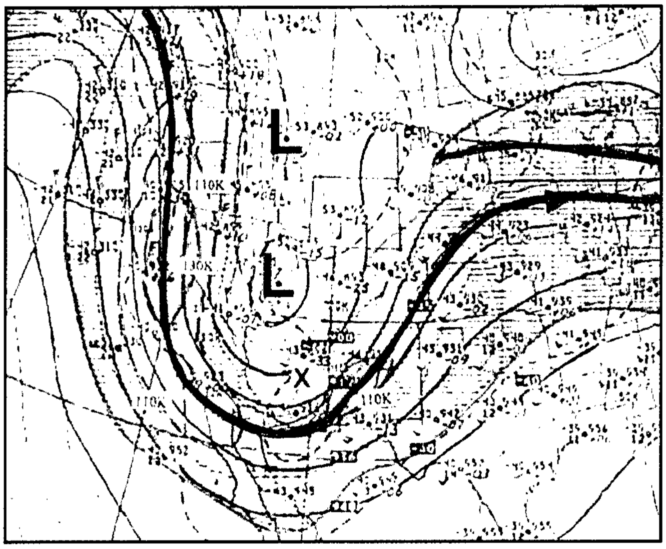

Figure 3-38. 300 mb, 0000Z/26 November 1983
Trough continues eastward. Main low has developed within base of trough (Twenty-four hours later from Figure 3-37).

Although not quite into the winter season, Figures 3-37 and 3-38 depicts a late November event that shows an ideal upper air regime for major storm development across the western and central CONUS. The 300 mb low shown west of Washington in Figure 3-37 is an old low that dropped southward from the Gulf of Alaska. In many cases studied, new low formation develops further to the south where there are tighter pressure and thermal gradients, PVA and wind speed maxima (Figure 3-38). Significant snow fell over the central and upper Great Plains with this system. In Figure 3-38, the older low will dissipate as upper-level energy is transferred to the southern system.

Split-Flow Cyclogenesis

Many major snowstorms and severe winter weather occurrences across the Rocky Mountains and Great Plains to the East Coast are associated with split-flow cyclogenesis that begin over the western CONUS. Forecasters may find it difficult at times to identify satellite deformation zones and vorticity comma cloud systems which are associated with these developing upper lows over the western CONUS. Mountain influences tend to dry out accompanying Pacific moisture which will produce ill-defined deformation zone and vorticity comma cloud systems. These cloud elements that compose a major comma cloud system become better defined when the storm system moves out of the Rocky Mountains and encounters Gulf moisture advection.

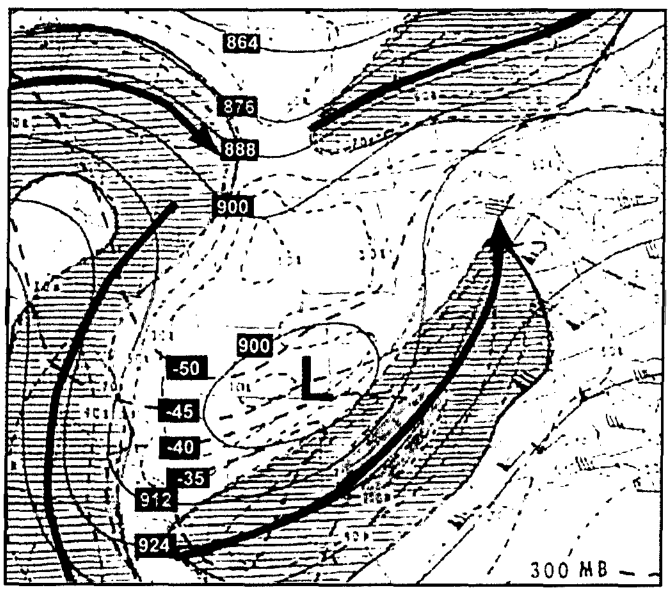

Figure 3-39. 300 mb, 0000Z/25 December 1982

Eastern Pacific troughs entering the western CONUS sometimes split due to continued southward digging of short wave impulses. The northern and southern polar jet branches are associated with split-flow events. The southern portion of the split slows its eastward movement as it often undergoes upper-level cyclogenesis. The northern polar branch and the accompanying short wave continue eastward. Figures 3-39 through 3-41 illustrate several examples.

All three of these events produced major winter storms including heavy snowfall and freezing precipitation over the southern and central Rocky Mountains and the Great Plains.

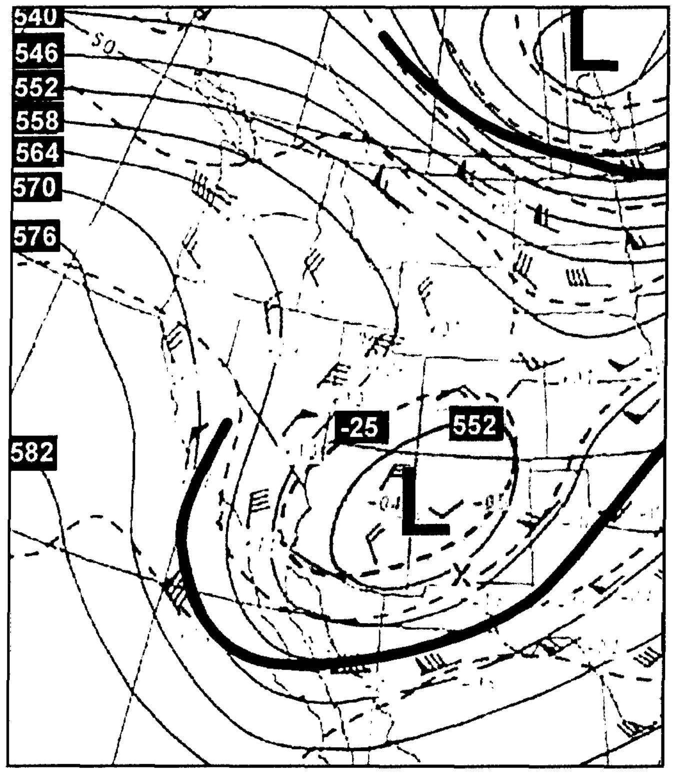

Figure 3-40. 500 mb, 0000Z/30 January 1982

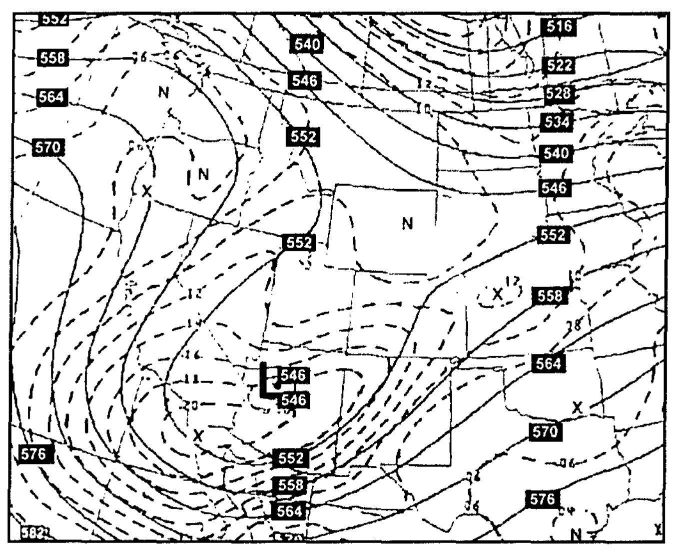

Figure 3-41. 500 mb HEIGHTS/VORTICITY Continued digging southward has split the westerly flow.

Great Basin High

A major feature during the cold season is the continued intensification of anticyclonic activity over the Great Basin area (Figure 3-42). The Great Basin High begins to appear in September; the number of highs reaches a maximum frequency of occurrence in December. This mountain-confined high is caused by cold air that has been trapped by the mountains (Rockies on the east and the Sierras on the west). Sea-level pressures rise as the cold air strengthens which results in anticyclogenesis. Typical development occurs when a ridge, following a Pacific mP cold front, is pinched off the North Pacific High system along the West Coast. Persistent stratus, fog and drizzle continues to be a problem over many valley and river areas due to minimal solar insolation and a day-to day strengthening of low-level inversions. Figure 3-42 depicts a typical Great Basin High regime. Several highs are often analyzed on surface charts; analyst may find it difficult to analyze for very high pressures in mountain areas.

A second Great Basin High regime occurs when continental polar (cP) ridging from western Canada drops southward (typically an Alberta High) across the Pacific Northwest and merges with maritime polar (mP) already in place over the Great Basin area (Figure 3-43). It is important to recognize the source region of the Great Basin High to determine the strength and persistence of low-level inversions (stratus, fog and freezing drizzle).

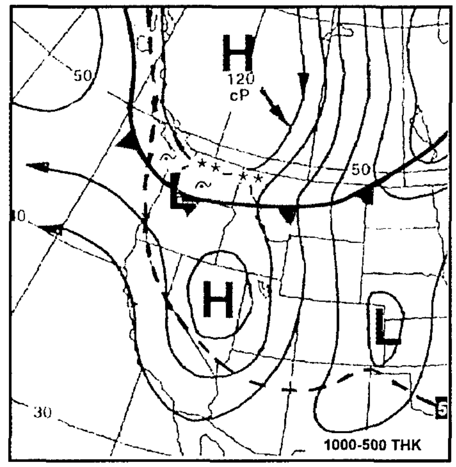

Figure 3-43. Typical Surface Model, Great Basin High

Great Basin High established over the western CONUS. A ridge extends northwestward across Washington and Oregon that is a setup for low ceilings and fog in the Columbia Basin area.

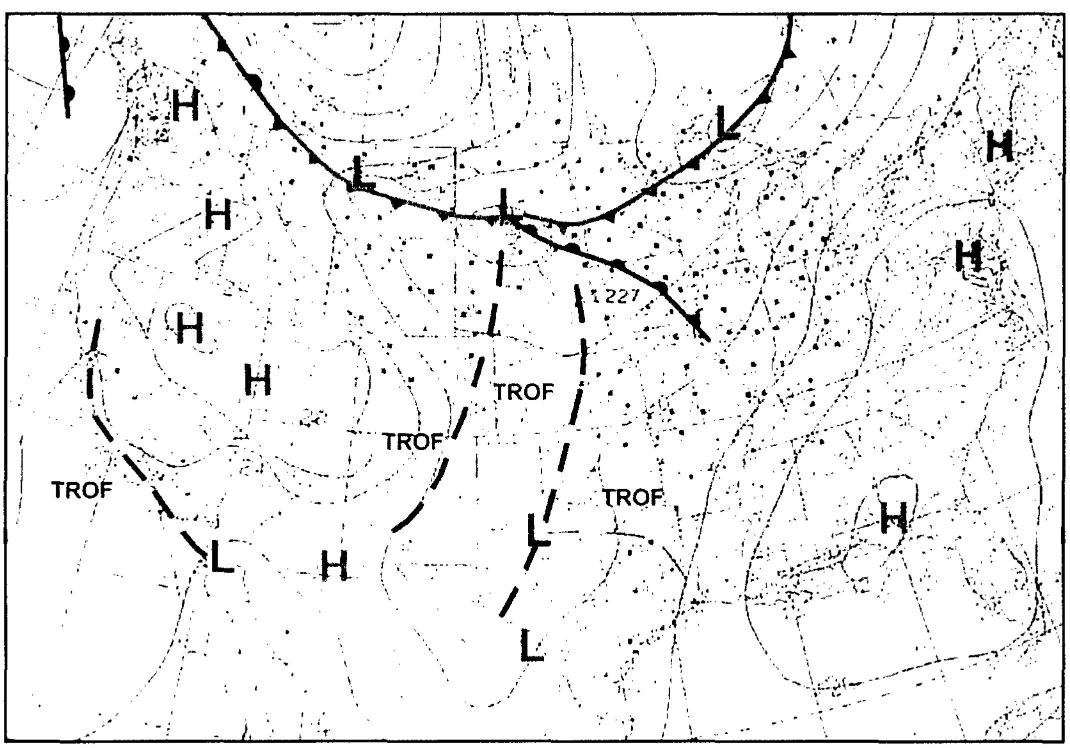

Figure 3-42. Surface, 0300Z/6 January 1999

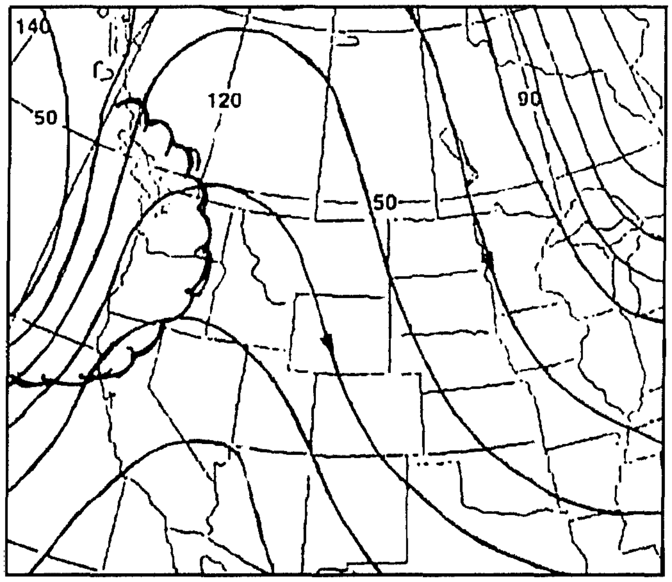

Figure 3-44. Typical 500 mb with Great Basin High

Upper-level ridge impact on the Great Basin High.

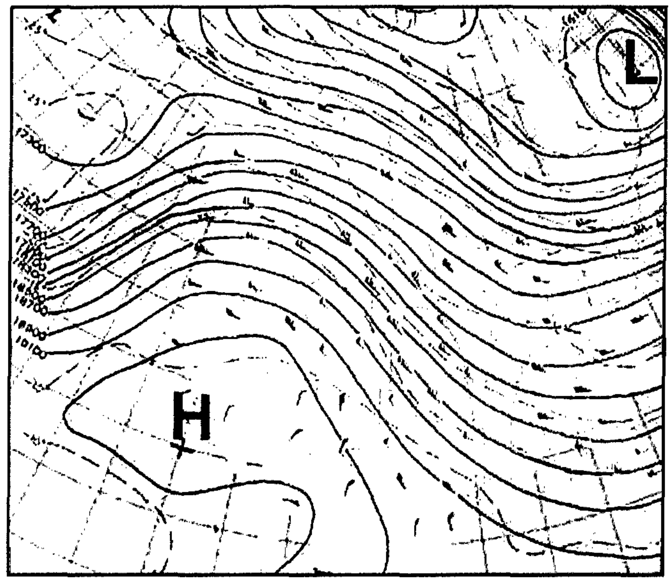

Figure 3-45. Example 500 mb with Great Basin High, 1200Z/26 December 1980

Great Basin Highs are strongest and most persistent when supported by a ridge aloft over the western CONUS as shown in Figures 3-44 and 3-45. Persistent low ceilings, fog and periods of drizzle are likely if this mid troposphere ridge continues for several days or perhaps for a week, especially if the air mass is shallow, continental polar (stronger inversions).

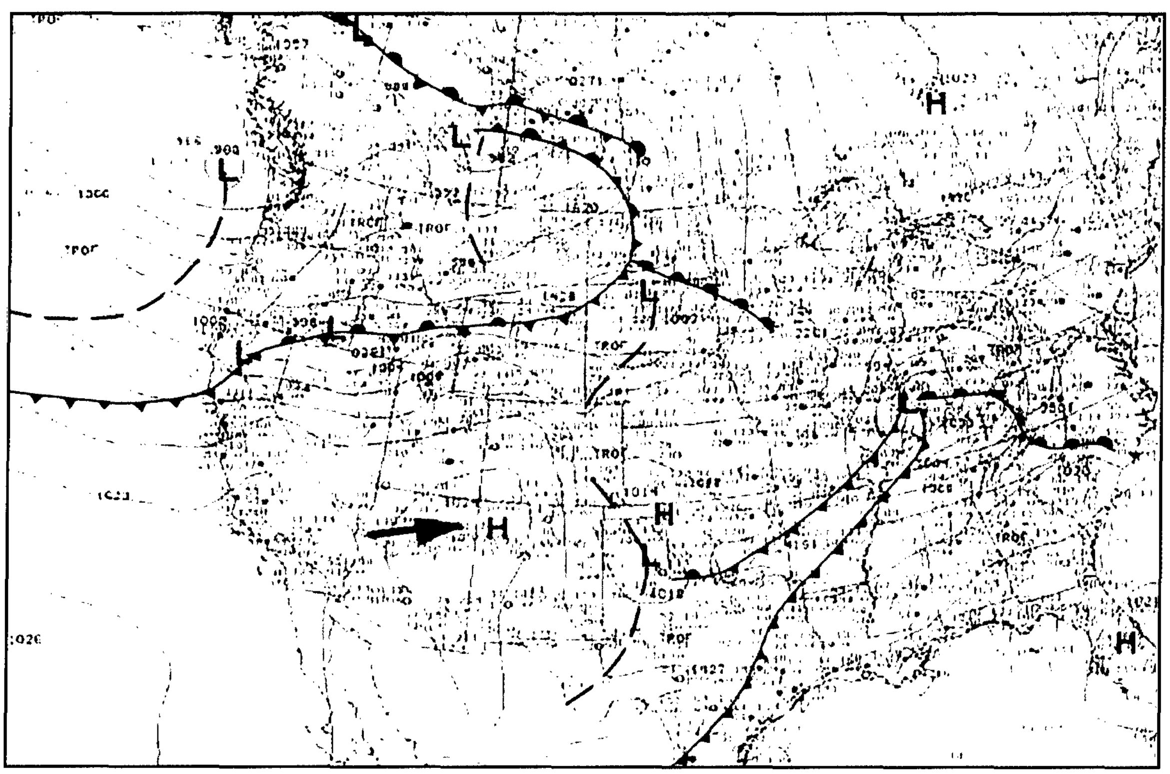

Figure 3-46. Surface, 1500Z/7 February 1999

Conversely, Great Basin Highs gradually weaken or dissipate over the mountains as increased low-level warming ahead of an approaching disturbance erodes the anticyclone (Figure 3-46). In Figure 3-46, the weakening Great Basin ridge shifted eastward into western Colorado and New Mexico in advance of a Pacific mP cold front (noted by the arrow). The high will reappear over the western CONUS after the front moves into the Great Plains. Figure 3-47 shows a second example where the Great Basin High has settled over the central Rocky Mountains.

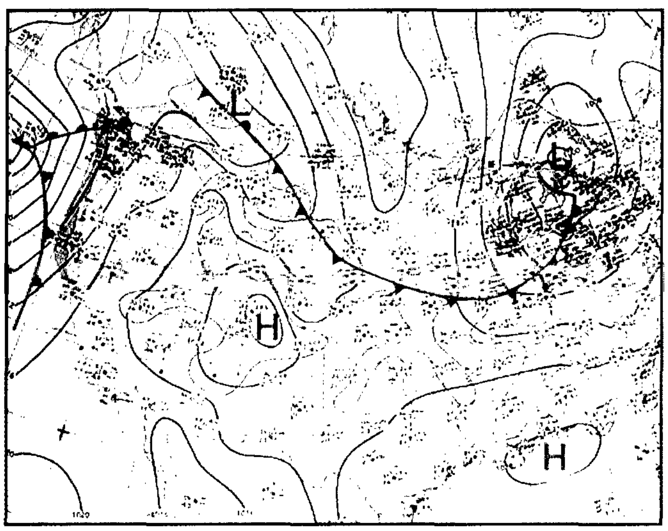

Figure 3-47. Surface, 1200Z/27 February 1980
Great Basin High shifted eastward in advance of a strong mP front approaching the West Coast.

Although named the Great Basin High because of its frequent appearance in that area (Figure 3-48), the high system's center may wander across the western CONUS. The system will move eastward as shown in Figure 3-47, but it never moves out of the mountains into the western Great Plains as an entity as depicted in Figure 3-48. Surface analyses will reveal that transitory post-cold frontal highs will either develop over the Great Plains or a ridge will pinch off of the Great Basin High as illustrated in Figure 3-48 (noted by the arrow). In Figure 3- 48, an mP ridge and high has developed over western Texas, however, the Great Basin High remains intact over the western CONUS.

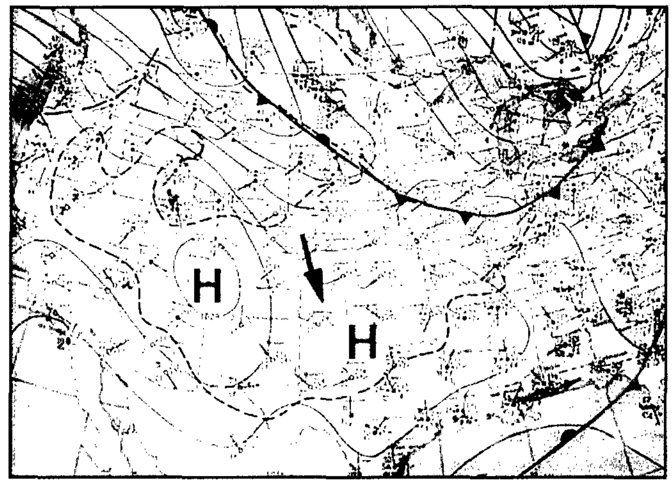

Figure 3-48. Surface, 1200Z/25 January 1984

Figure 3-49 illustrates a Great Basin High model and the various weather phenomena associated with this annual regime. Significant events such as persistent fog in the San Joaquin and Sacramento Valley areas, low ceilings, fog, drizzle (and freezing drizzle) in the Columbia Basin and Snake River valley regions and strong warm downslope winds east of the Montana and Wyoming Rocky Mountains occur with this regime.

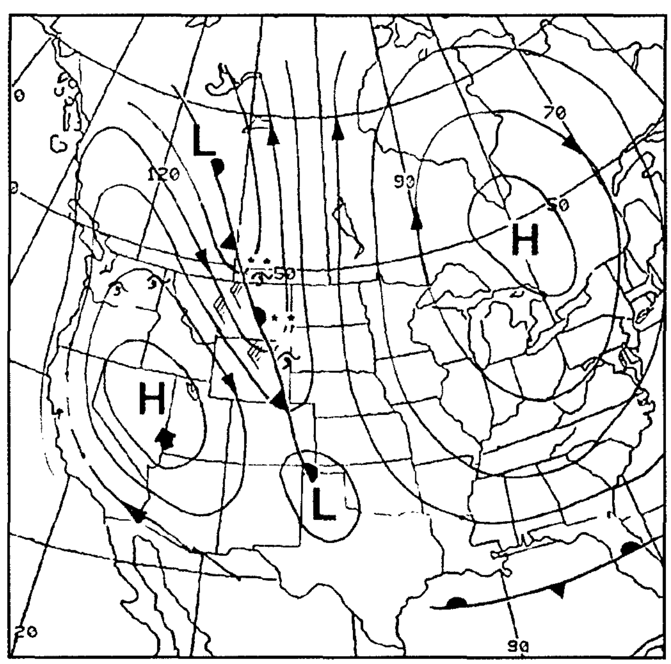

Figure 3-49. Great Basin High Model

The stationary front shown across eastern Montana and Wyoming in Figure 3-49 appears frequently during the winter months. The front separates the mountain-confined Great Basin High and transitory Canadian polar air masses. The front fluctuates back and forth across central and eastern Montana and Wyoming when frontal lows either develop over the area or drop southward from Canada bringing in fresh outbreaks of Canadian polar air. Forecasters must keep continuity on the strengths, trends and movements of these two anticyclonic systems to determine frontal locations and expected weather conditions. Distinct weather events occur on either side of the frontal zone as will be shown in the subsequent pages.

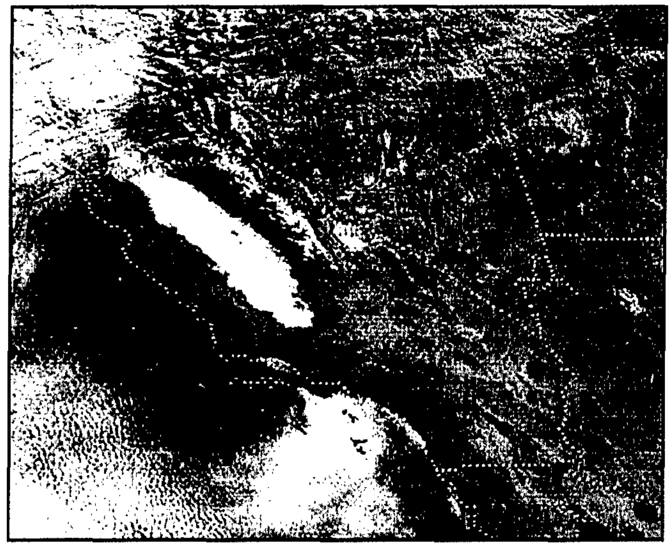

Figure 3-50. GOES-W VIS, Late January
Persistent fog in the San Joaquin and SacramentoValleys.

Great Basin High Weather Phenomena

Further discussion of the various weather conditions that "set up" when the Great Basin High becomes established over the western CONUS will now be presented in the following examples.

Fog and Freezing Precipitation

Figure 3-50 typifies the fog regime over the San Joaquin and Sacramento Valley areas when the Great Basin High and its low-level inversions are in place over the valleys (see Figure 3-51). The fog will improve somewhat during the heating hours lifting to low stratus ceilings; the fog thickens when radiational cooling begins by late afternoon. This fog regime will continue daily for several days until the Great Basin High dissipates or shifts eastward in response to warm air advection ahead of an approaching Pacific storm system. In Figure 3-50, note the snow cover over the Sierra Nevada Mountains.

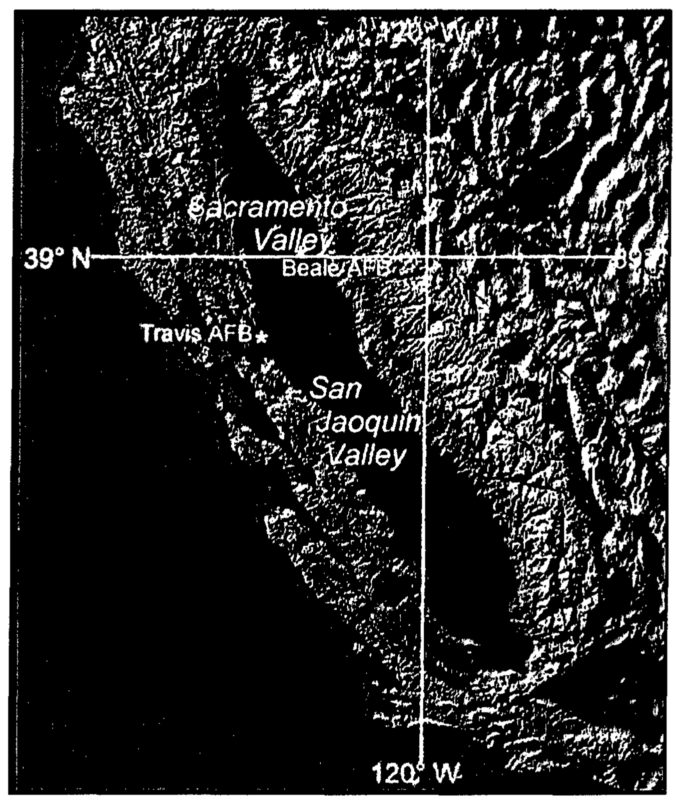

Figure 3-51. San Joaquin and Sacramento Valleys
Note the elongated "bowl" in interior California surrounded by mountains. It's easy to see why there can be "trapped" persistent fog.

The Columbia Basin area east of the Washington Cascades, as shown on the geographical map in Figure 3-52, may experience continuous days of low ceilings, fog and drizzle when a cP ridge, extending northward from the Great Basin High, lies across the basin. When the source region is continental Polar air from western Canada, then the inversion becomes very strong and "traps" low-level moisture in basins and valleys. The high will persist for days until there is an air mass change. Freezing drizzle is generally a common diurnal event.

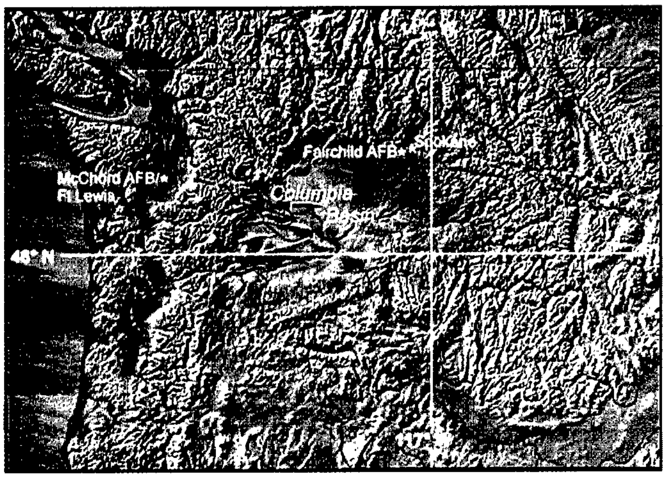

Figure 3-52. Topographic Map of the Columbia Basin
Spokane and the Fairchild AFB area experience many days with persistent fog and stratus.

Freezing drizzle and fog is a common occurrence as just shown. Freezing rain associated with offshore storms creates a hazardous condition for locations within the Columbia Basin as will be shown in Figures 3-53 through 3-56. This event will continue until the storm system moves into western Canada as shown in the model example, Figure 3-53 below. Rain falls along the coast to the windward side of the Cascades, snow falls in the mountains and freezing rain occurs within the Columbia Basin when warmer air overruns the shallow cold dome. In an actual event, Figures 3-54 through 3-56, freezing rain was widespread over the Columbia Basin as noted in Figure 3-56. In Figure 3-54, the Great Basin ridge appears over eastern Washington, and Oregon and eastward. At the 500 mb level (Figure 3-55), a PVA lobe extending southeastward from the cold core Aleutian low has brought moisture, relatively warmer air, and vertical lift across most of Washington; freezing rain was observed at all interior reporting locations (Figure 3- 56).

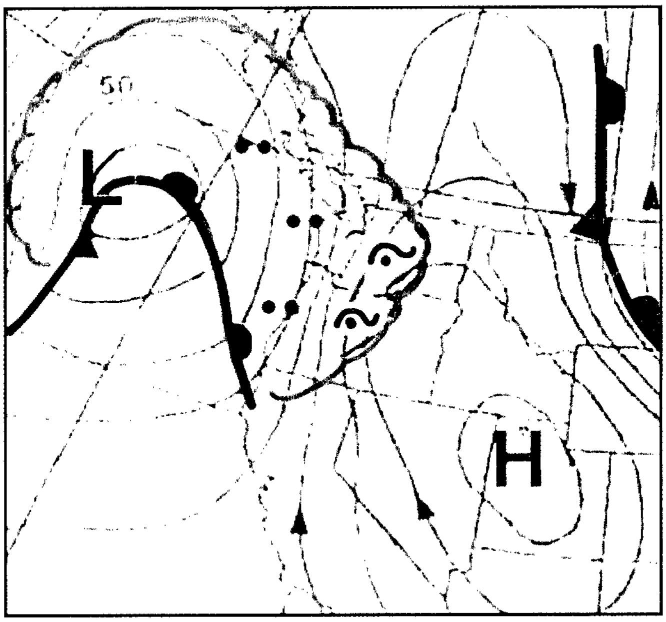

Figure 3-53. Freezing Rain Scenario for the Columbia Basin

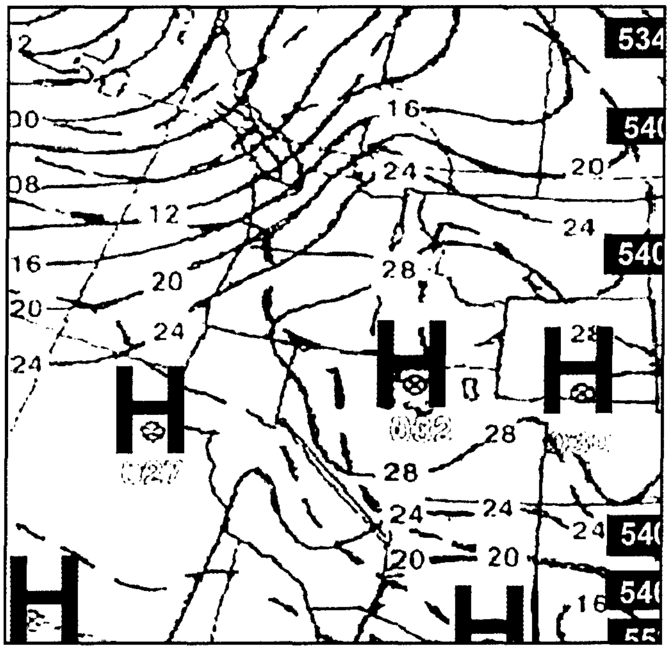

Figure 3-54. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/4 March 1993

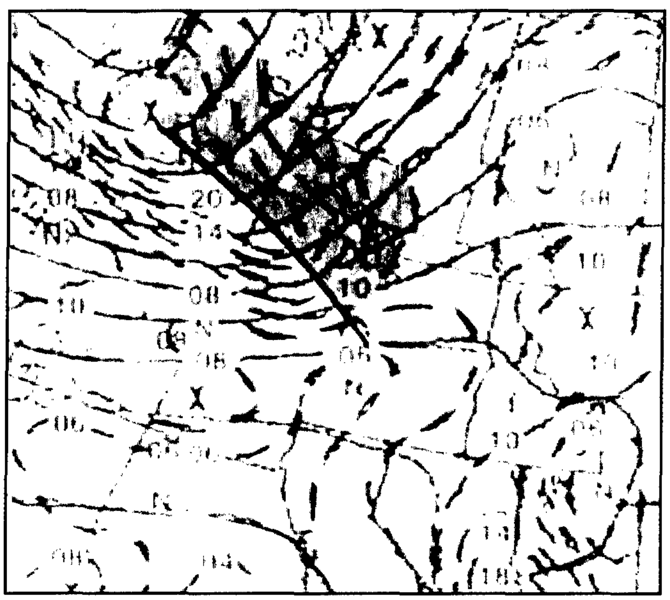

Figure 3-55. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/4 March 1993

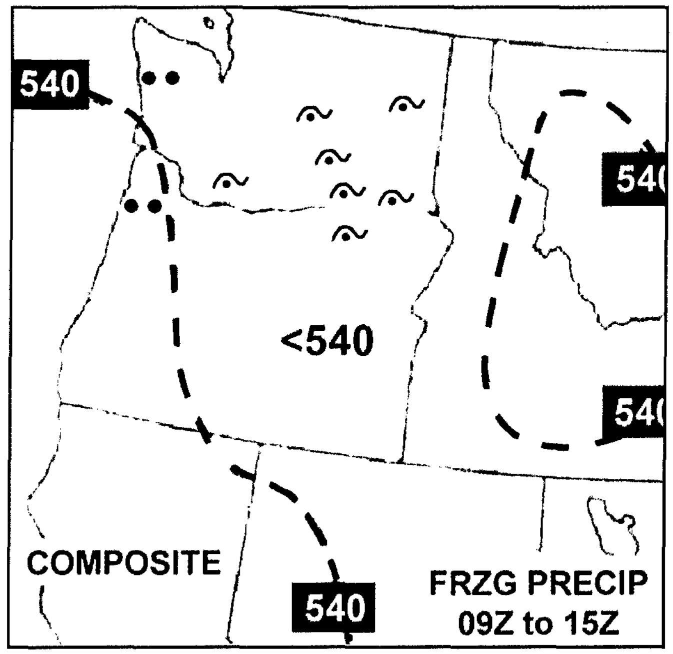

Figure 3-56. 1000-500 mb Thickness/Freezing Precipitation, 0900Z/4 March 1993-1200Z/4 March 1993

Freezing rain occurred over the Columbia Basin. Rain occurred west of the Cascades.

Upslope/Downslope (Associated with Polar Front)

The illustration shown in Figure 3-57 was presented earlier in the Great Basin model. It is shown again to focus on the associated weather events with this regime. The continental polar front aligns northwest to southeast and becomes quasi-stationary as the Great Plains high slides southeastward. Waves often appear on this frontal boundary. This quasi-front moves back and forth east of the Rocky Mountains. The Great Falls, Montana area may experience significant and rapid changes in the weather as the quasi-stationary front fluctuates across their location i.e. low ceiling, fog, and cold temperatures becoming clear or partly cloudy, significantly warmer and windy. As depicted in Figure 3-57, a dry, warm westerly flow is established west of the front. Strong downslope winds are likely to occur. East of the front, a cold, moist flow with low ceilings, patchy fog and light snow or drizzle will occur.

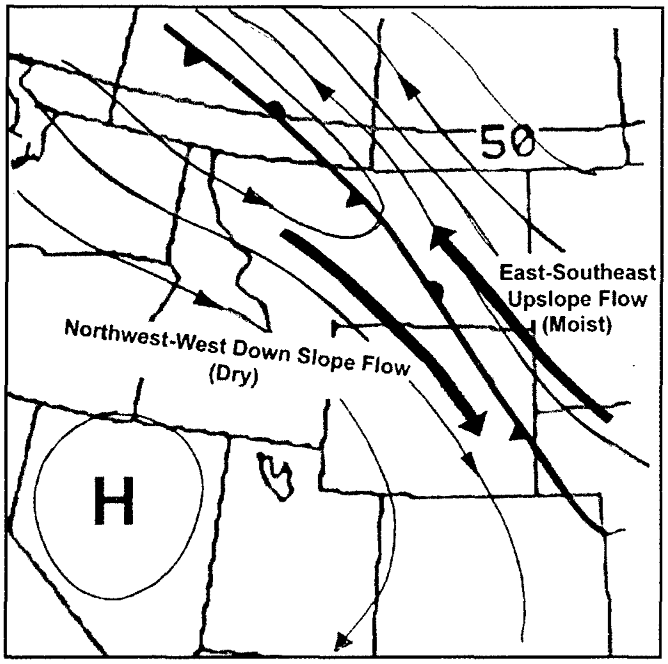

Figure 3-57. Upslope and Downslope Regime Model

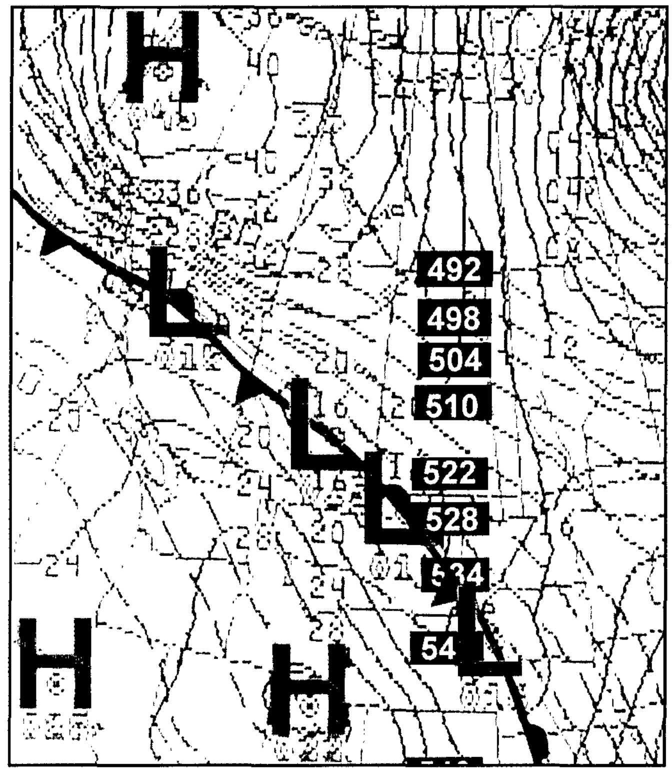

Figure 3-58. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/5 January 1999
Quasi-stationary polar front east of the Rockies.

Figure 3-58 illustrates a typical quasi-stationary frontal system along the Canadian and northern CONUS Rocky Mountains during the winter season. Several frontal lows are noted. Approaching upstream short waves will often initiate frontal waves along this boundary (i.e. Alberta Lows) and a new surge of fresh Canadian air will slide rapidly southward following the frontal wave. More discussion on these regimes will be presented in Chapter 4.

Figures 3-59 shows typical surface wind reports east of the Rocky Mountains (downslope). A frequent downslope wind event occurs along and east of the Rockies. This is just one of several setups for the formation of one of the Notorious Wind Boxes, the Livingston Box. Livingston Box wind directions are from a southwest component; cold air advection wind directions are from a northwest component. The strong southwest surface winds decrease in strength as they move away from the mountains (only Livingston Box winds; cold air advection winds will continue eastward). Figure 3-60 shows the reporting stations affected by strong, katabatic winds. The Livingston, Montana (LVM) region is notorious for strong winds that may continue for several days and do not let up (less than 35 knots) during the radiational cooling period. Sometimes, the Livingston Box will extend southward into northern Colorado and will affect the Denver (DEN) and Boulder (BJC) locations.

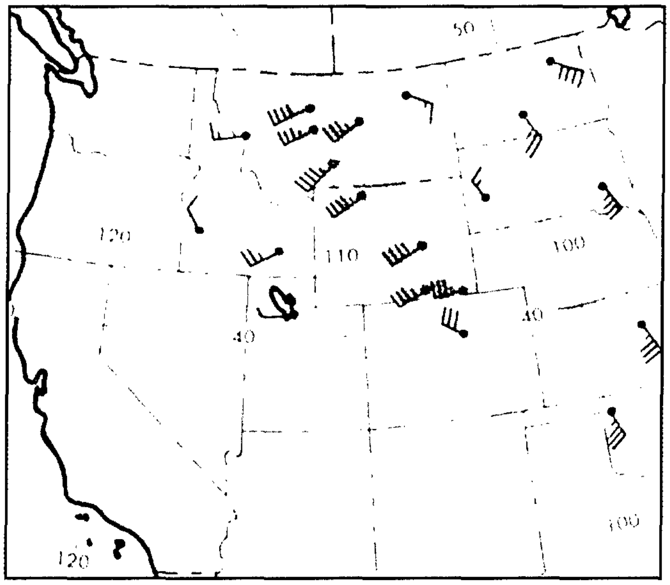

Figure 3-59. Livingston Box (Downslope)

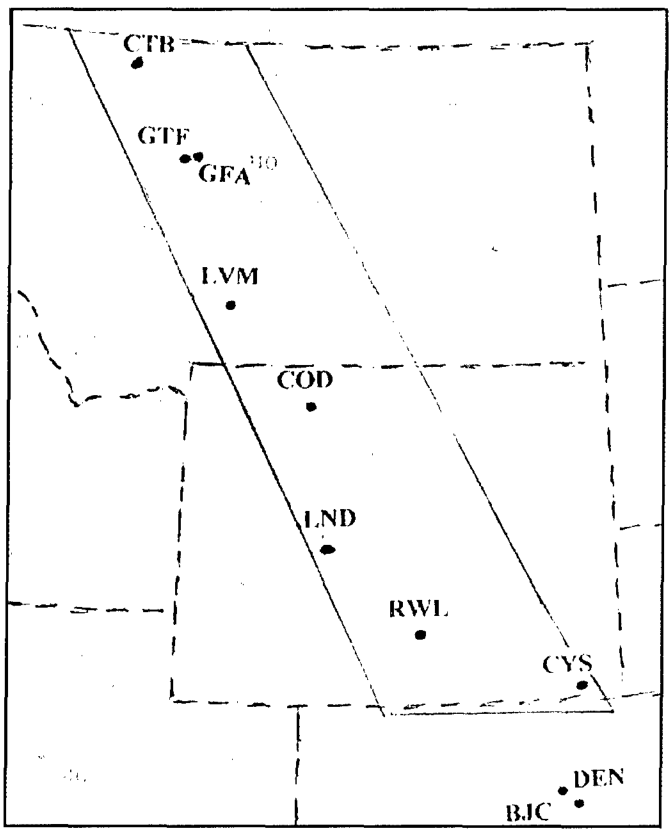

Figure 3-60. Stations in the Livingston Box
Reporting stations affected by strong katabatic winds.

Figure 3-61 depicts a common cloud regime associated with the stationary polar front. This visible satellite image shows upslope low clouds over eastern Montana, western Nebraska and South Dakota (noted by the dark arrow). Light precipitation is likely (snow and/or freezing drizzle). The white arrow points to an approaching short wave.

Figure 3-61. GOES-E VIS, Late February

Arctic and Polar Air Mass Movements

Polar and arctic air masses begin to spread westward to and across the Rocky Mountains as central pressures increase and the cold domes expand in height. A strong moist upslope regime is established east of the front, which results in frequent snowfall over the Montana and northern Wyoming Rocky Mountains. Also, a tight southeast to northwest pressure gradient occurs as shown in Figure 3-62. Strong surface winds are not routinely observed because the winds are moving uphill. Strong winds are likely in the higher elevations and mountain passes. Figures 3-63 and 3-64 illustrate a typical model presentation of Pacific moisture spreading southeastward over the shallow cP dome.

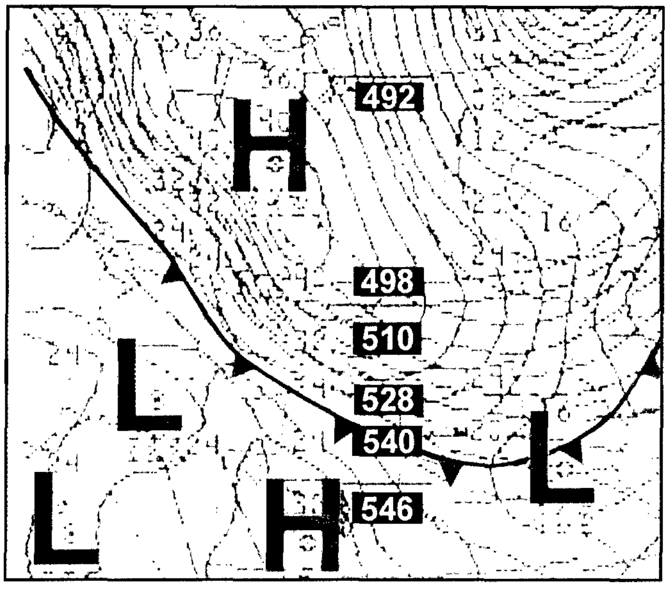

Figure 3-62. Surface, 1200Z/5 January 1999

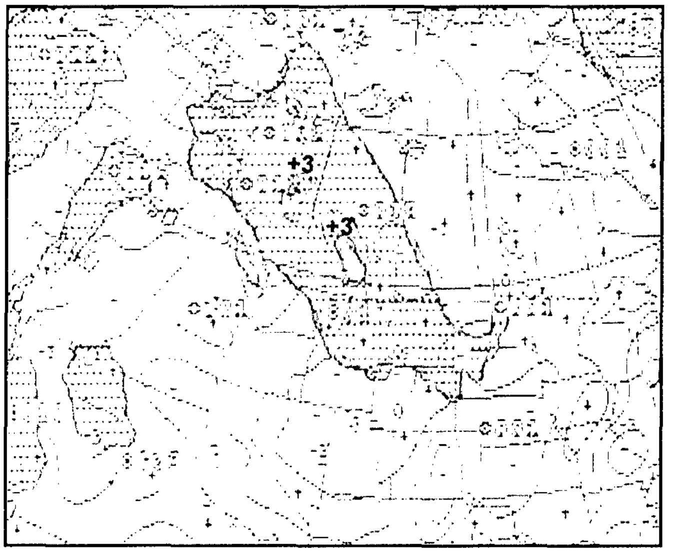

Figure 3-64. 12HR PRECIP/700 mb VERT VEL, 1200Z/5 January 1999

Shaded areas depict potential for precipitation. A swath of light snow occurred from the Northern Rockies to Nebraska/Iowa within 24 hours.

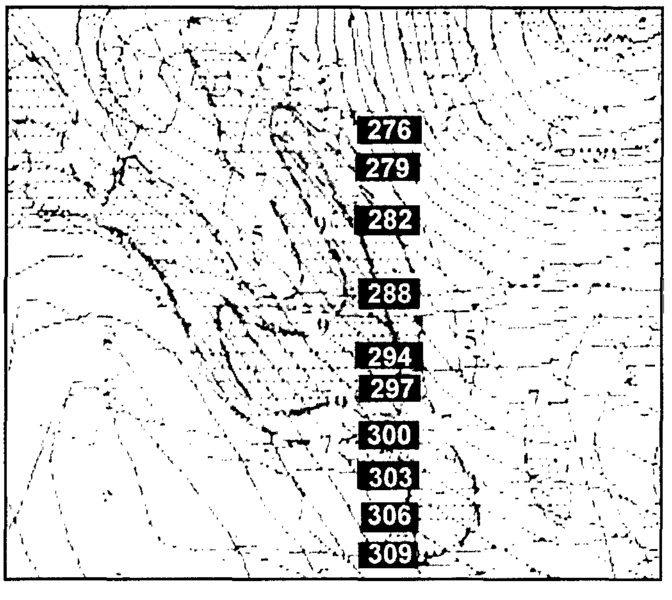

Figure 3-63. 12HR 700 mb HEIGHT/REL HUMIDITY, 1200Z/5 January 1999

Pacific moisture spreading southeastward over shallow cP air across the Northern Rockies.

Arctic and polar air masses are more likely to push west of the Rocky Mountains in January and February but may occur in December as shown in Figures 3-65 and 3-67. Arctic air intrusions into the Pacific Northwest may produce ice and snowstorms. They are usually associated with short waves or closed upper lows that move southward from western Canada as shown in Figure 3-66.

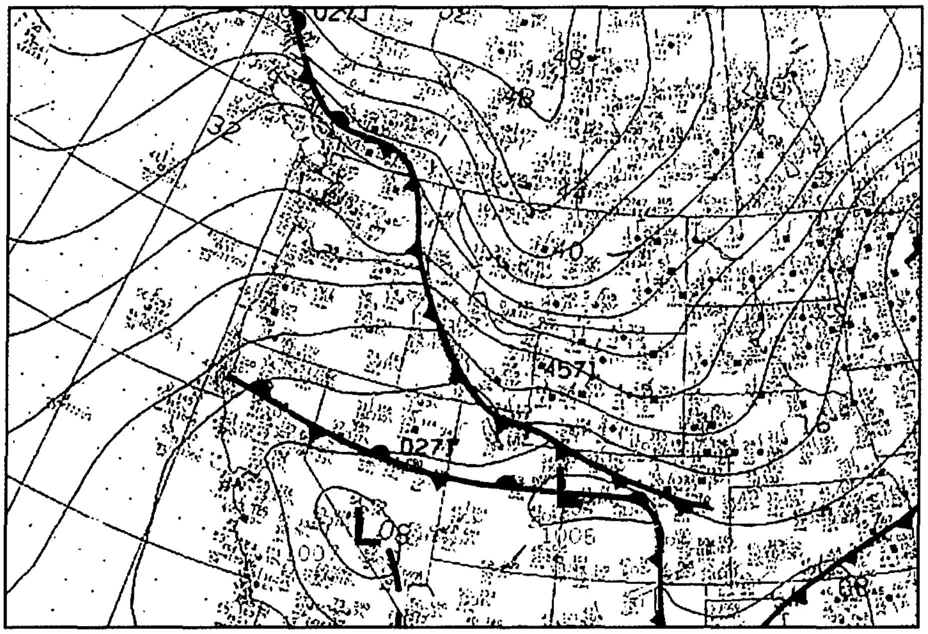

Figure 3-65. Surface, 0000Z/19 December 1998

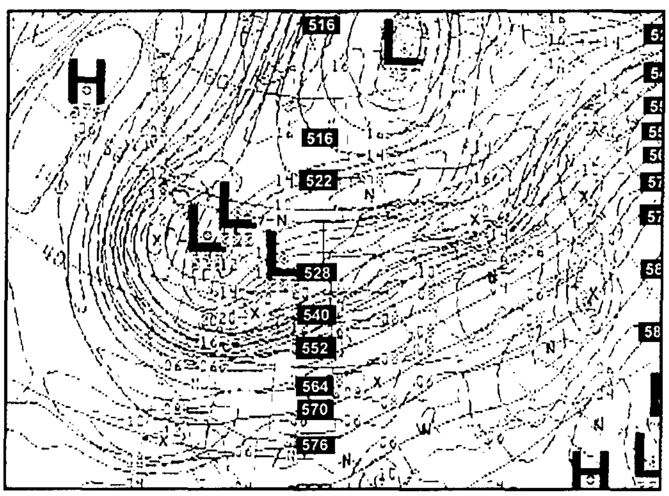

Figure 3-66. 500 mb HEIGHTS/VORTICITY, 0000Z/20 December 1998

In Figure 3-67, arctic air has spilled over the Rocky Mountains and has reached to the coast. The Washington and Oregon coastal stations are subject to snow and freezing precipitation under arctic air.

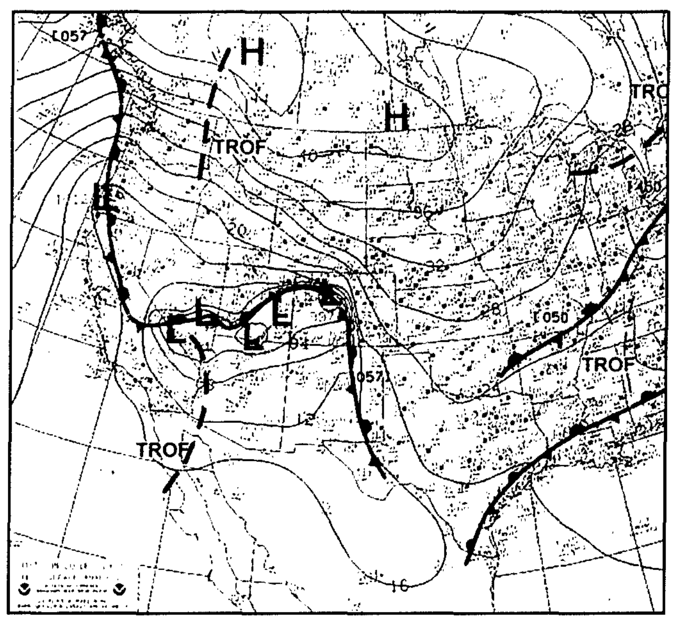

Figure 3-67. Surface, 0300Z/20 December 1998

A frontal feature that occurs during the winter is noted over southern Colorado and New Mexico as shown in Figure 3-68. The "frontal kink" occurs when transitory cP Alberta Highs drop southward across the Great Plains while the mountain-confined Great Basin High remains in place. Forecasters should not predict this frontal kink or wave to develop into a storm system unless there is an approaching short wave. Upslope conditions prevail east of the wave generally over northwest Texas, eastern New Mexico and Colorado. Low stratus, fog and light snow and drizzle (often, freezing drizzle) will occur as shown in the insert in Figure 3-68. Forecasters should not be in a hurry to forecast improvement during the heating hours; the light precipitation may persist as long as the upslope regime continues. This event will end when the transitory cP high moves far enough eastward to allow a return of warmer air within a southerly flow over western Texas and the southern Rocky Mountains. Notice in Figure 3-68 that a northern Great Plains ridge has pinched off the high pressure cell over Idaho; the Plains high will become an entity and move eastward following cold FROPA.

Non-Convective Surface Wind Regimes (Notorious Wind Boxes)

In this section, the wind areas affecting the western CONUS will be shown. Again, as a reminder, strong surface winds are likely to occur anywhere when synoptic conditions are favorable.

Forecasting strong non-convective surface winds over the western CONUS is often a challenge especially during the winter and spring months. Coastal and mountain areas have a strong influence on the strength of surface winds. Another factor is that Pacific upper troughs often undergo changes across the mountains from the Cascades/Sierras to the Rockies due to terrain effects. Deepening trough results in surface cyclogenesis in mountain areas that may produce strong orographic and gradient winds. Strong, cold air advection winds, will occur anywhere over the western CONUS (≥35 knots) when conditions are favorable. There are, however, several "notorious" wind areas (boxes) identified many years ago over the CONUS that are included in this Technical Note. Figure 3-69 shows these Notorious Wind Boxes.

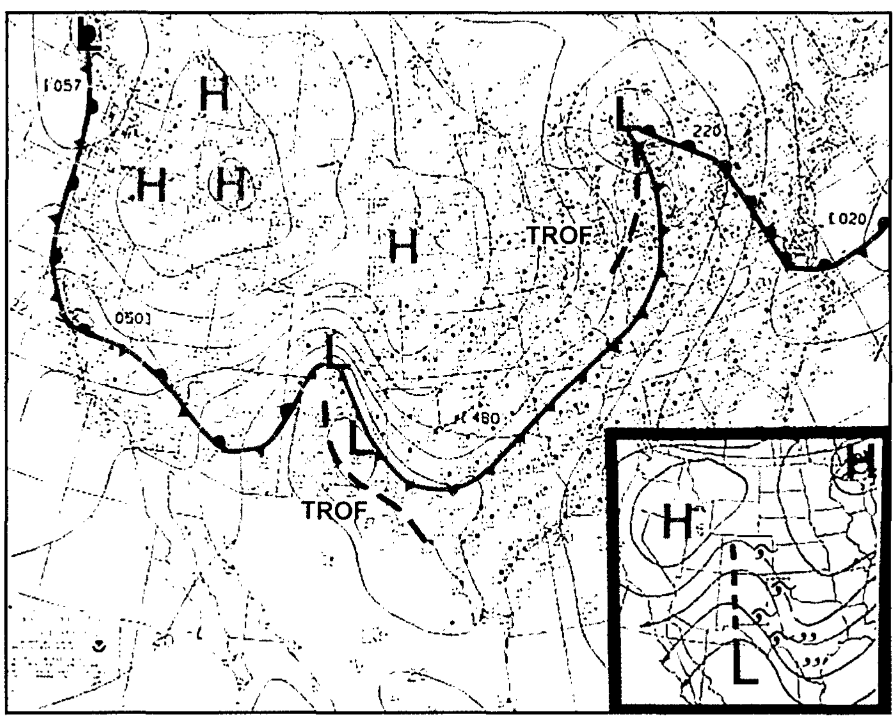

Figure 3-68. Surface, 1500Z/ 21 December 1998
Arctic air has pushed to the Pacific Coast.

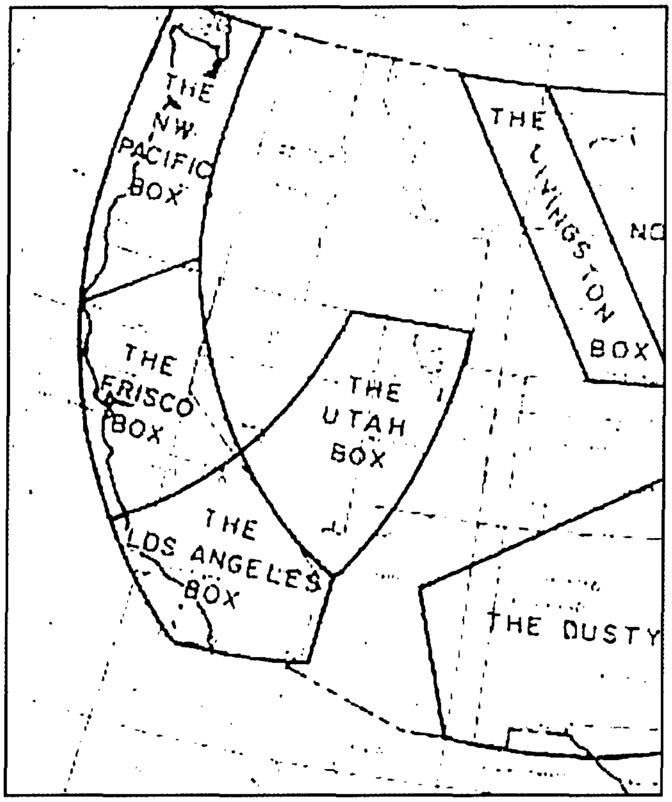

Figure 3-69. Notorious Wind Areas (Boxes) Map depicts areas frequently affected by strong non-convective surface winds (> 35 knots) across the CONUS.

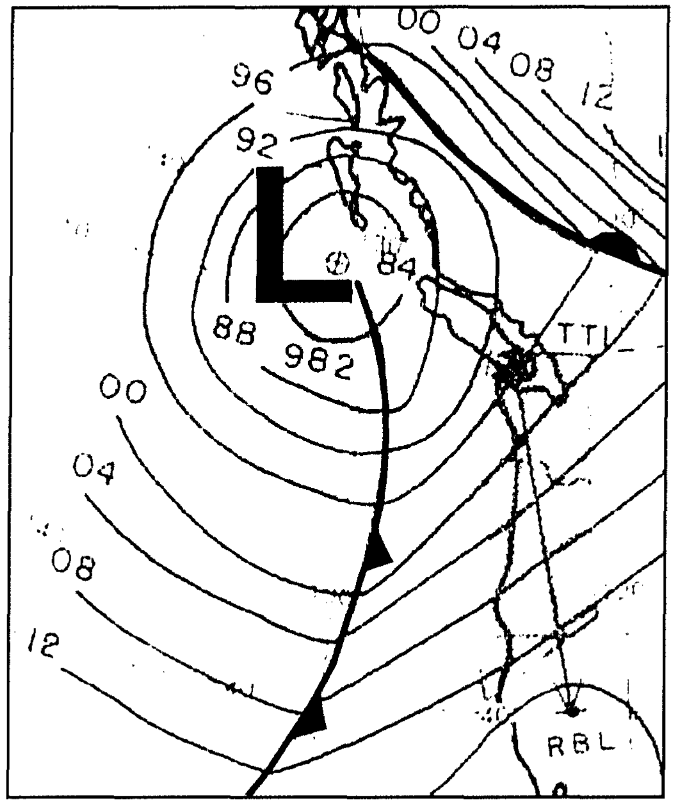

Figure 3-70. Northwest Pacific Box

Pacific Northwest Box

The Northwest Pacific Box is associated with major storm tracks (Figure 3-70). When large-scale storm systems move through the eastern Pacific on a course along the Pacific Coast between 40° and 50° N latitude, strong winds begin within the box shortly before the system's arrival and may continue for a period of up to 24 hours. Figure 3-71 depicts coastal reporting stations affected by strong winds. Hourly buoy reports are available over the ocean areas. Figures 3-72 and 3-73 show two examples of strong isobaric gradients over the Pacific Northwest that would generate strong surface winds.

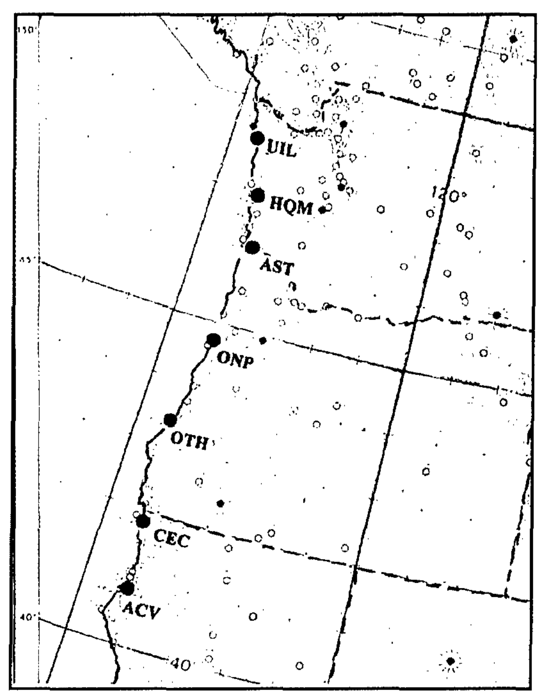

Figure 3-71. Stations in the Northwest Pacific Box

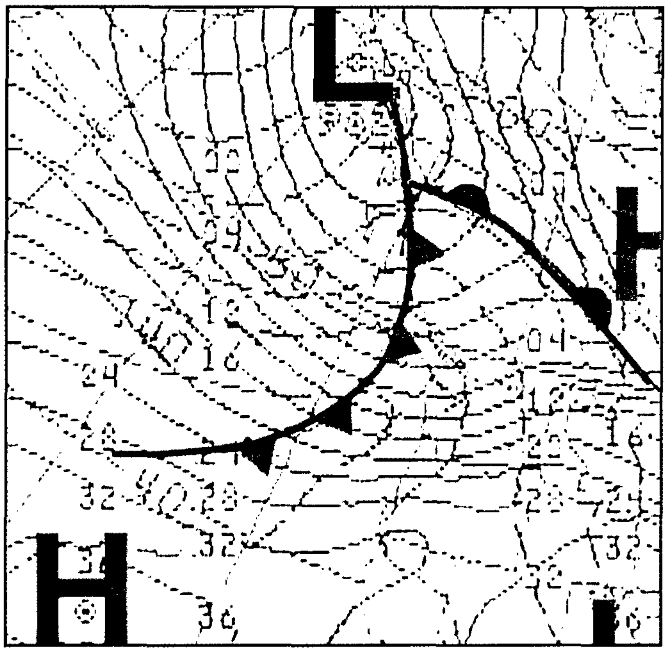

Figure 3-72. 12HR MSL PRES/1000-500 mb THKNS, 1200Z/2 February 1999

Tight pressure gradient with cold front approaching.

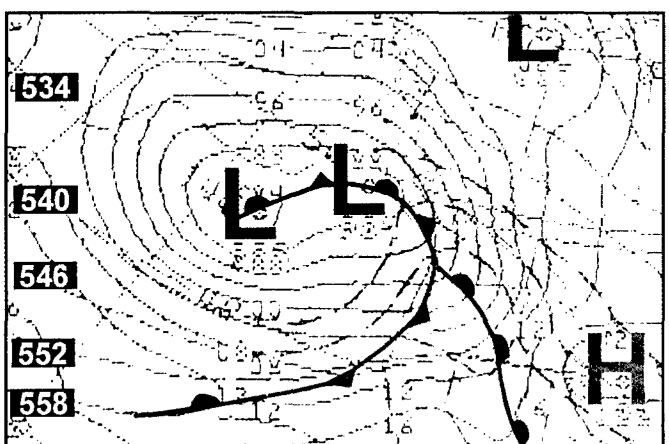

Figure 3-73. 12HR MSL PRES/1000-500 mb THKNS, 0000Z/18 January 1999

Strong surface winds occurred over the Pacific Northwest.

The Livingston Box was presented earlier in this chapter. Forecasters should determine the difference between the Livingston Box and cold air advection (CAA) surface winds. Strong surface winds may occur over a large region of the western CONUS as shown in the following illustrations. In Figure 3-74, a strong polar jet lies over the northern Rockies and Great Plains. In Figure 3-75, a strong surface pressure gradient is shown over the Great Plains and the northern Rockies. A wind outbreak (>35 knots), associated with the polar jet, lowered to the surface.

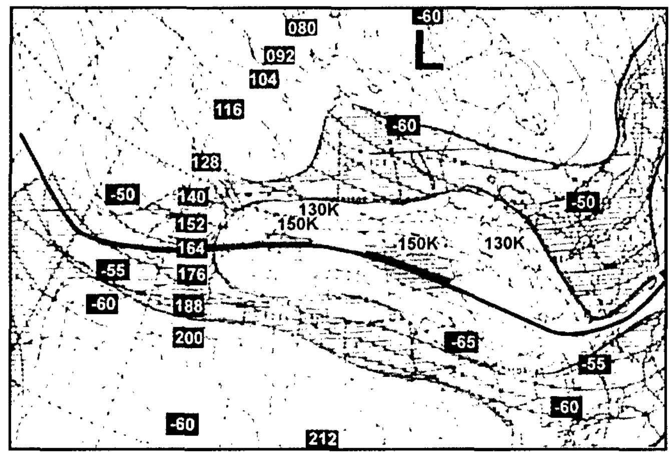

Figure 3-74. Strong Polar Jet at 300 mb, 1200Z/ 17 January 1982

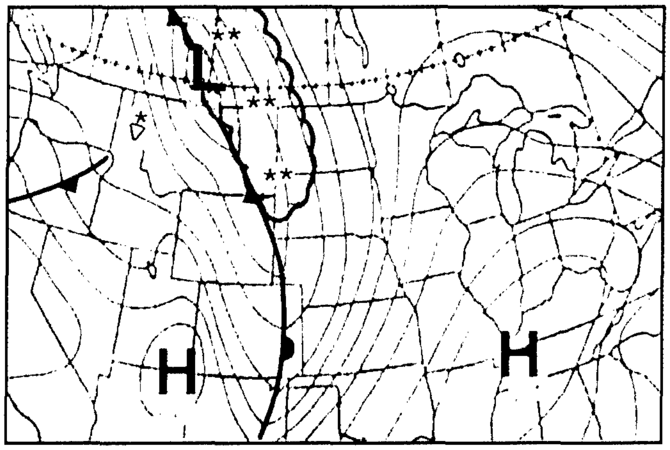

Figure 3-75. Surface, 1200Z/17January1982
Surface winds >35 knots reported from Montana to New Mexico.

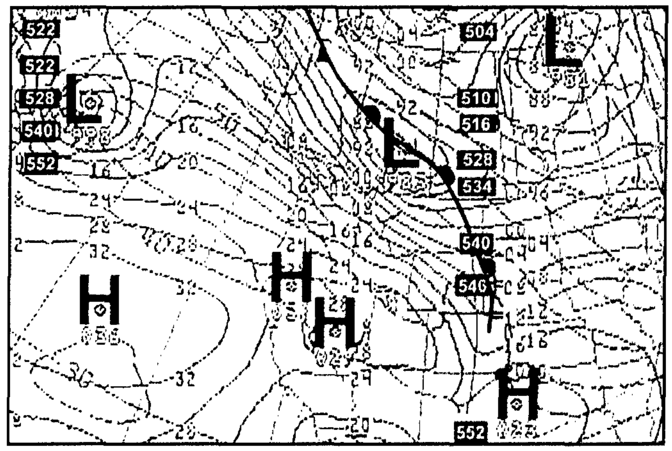

Figure 3-76. MSL PRES/1000-500 mb THKNS, 0000Z/3 February 1999
Strong pressure gradient from the Pacific Northwest to the northern Rockies.

Another strong wind regime that affects a large area from the Pacific Northwest eastward to the Great Plains is shown in Figures 3-76 and 3-77. Alberta Lows develop along the polar front (Figure 3-76) in response to an approaching short wave and continue to deepen over the northern Great Plains (Figure 3-77). The pressure gradient strengthens east of the Rocky Mountains. It generally is the beginning of a strong cold air wind outbreak that affects eastern Montana, Wyoming and Colorado and into the northern and central Great Plains. Often, the initial wind event begins with the Livingston Box (Figure 3-76). Twelve hours later in Figure 3-77, the Northern Plains Box began activating as the deepening low moves into the northern Great Plains.

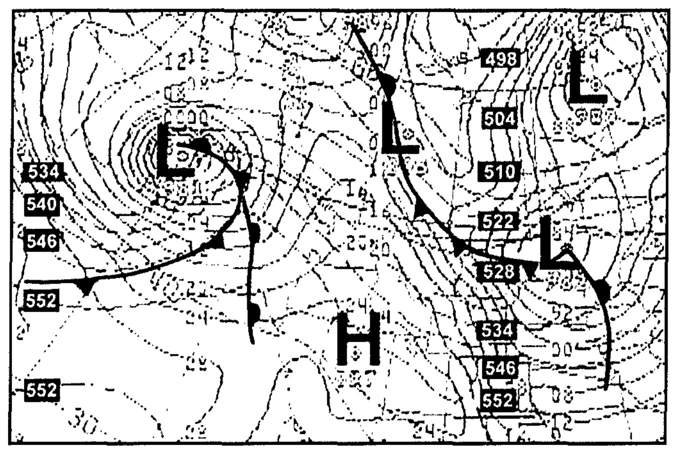

Figure 3-77. MSL PRES/1000-500 mb THKNS, 1200Z/3 February 1999
Strong gradient has shifted eastward as low tracks southeastward.

Frisco Box

The Frisco wind regimes occur when low pressure systems enter the West Coast over California. The synoptic pattern shown in Figure 3-78 activates a southerly wind event over central and northern California. Figures 3-79 and 3-80 respectively show the low-level and mid-level maximum winds.

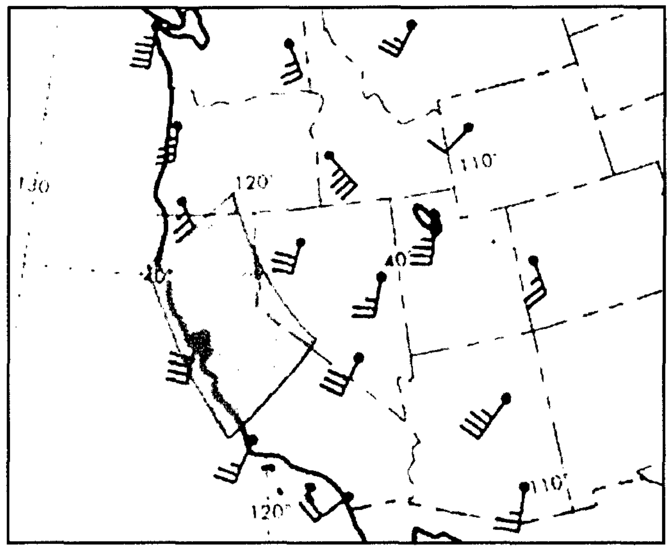

Figure 3-79. Frisco Box Low-Level Maximum Winds
Strong winds usually begin when the storm center is within 200 miles of the coast

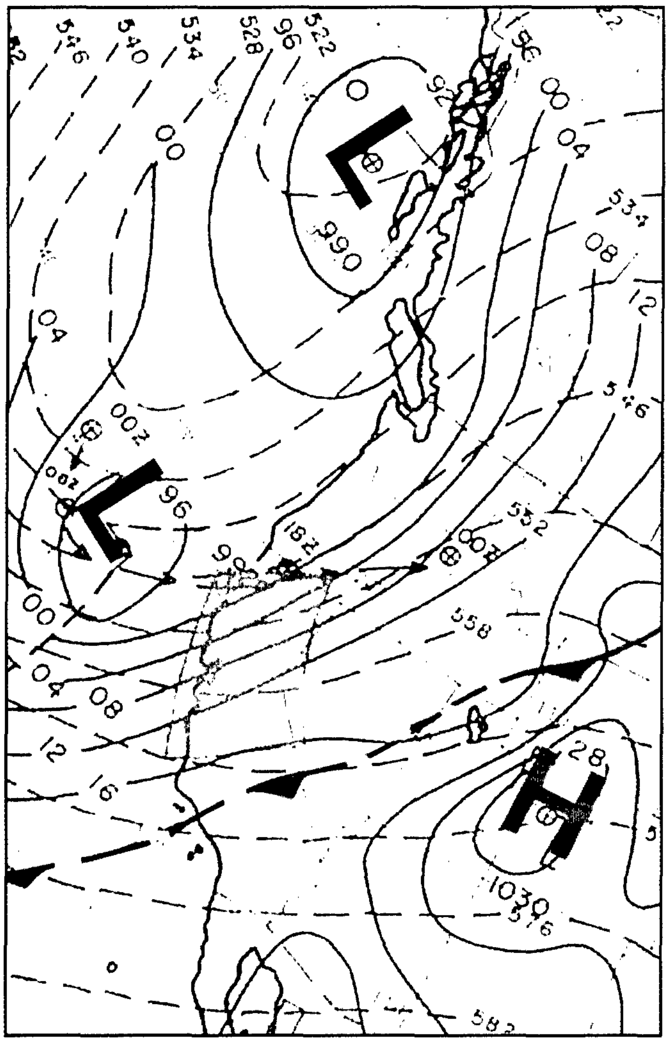

Figure 3-78. Frisco Box Surface Example
The tight pressure gradient ahead of the approaching low will produce winds in excess of 35 knots along the coast. Great Basin High appears over Colorado.

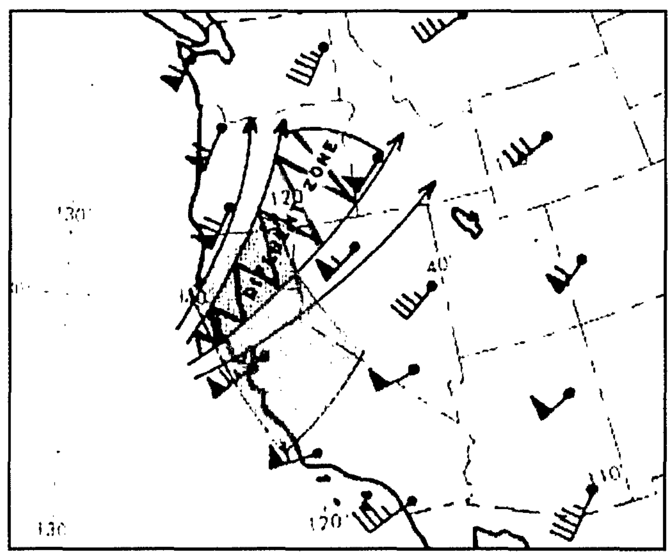

Figure 3-80. Frisco Box Mid-Level Maximum Winds
Southwest difluent wind flow within the mid-levels enhances strong surface winds.

Los Angeles Box

Two synoptic patterns that produce strong northwesterly to northerly surface winds are shown in Figures 3-81 and 3-82. In Figure 3-81, strong northwesterly downrush winds associated with a digging upper trough occurred following cold FROPA. Surface pressure gradients are not always very tight over California and that may mislead forecasters that strong westerly winds will not occur. Figures 3-82 and 3-83 show a north to northeast wind flow that extends into the upper troposphere. This is the basic synoptic regime for "Santa Ana" wind outbreaks. Figure 3-84 illustrates a mid-level synoptic pattern favorable for Santa Ana winds

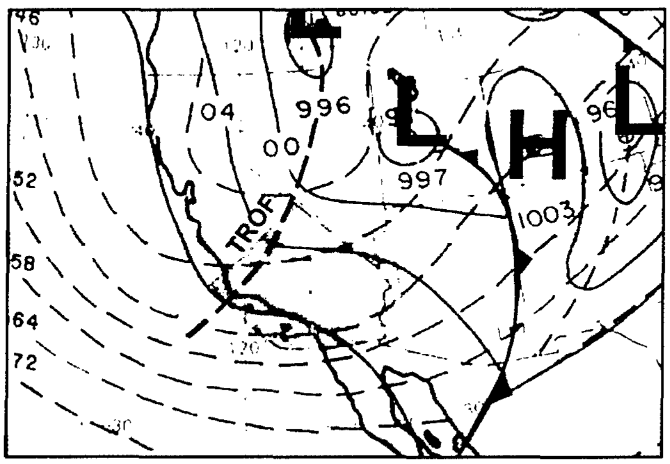

Figure 3-81. Los Angeles Box Surface Example 1

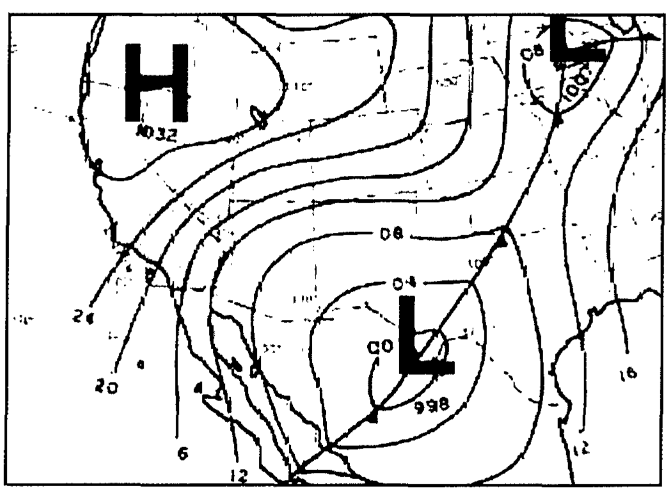

Figure 3-82. Los Angeles Box Surface Example 2

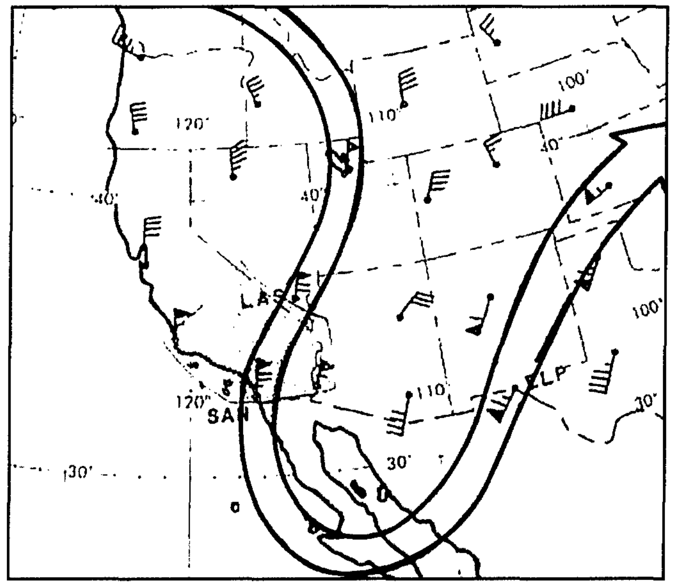

Figure 3-83. Los Angeles Box Mid-Level Maximum Winds

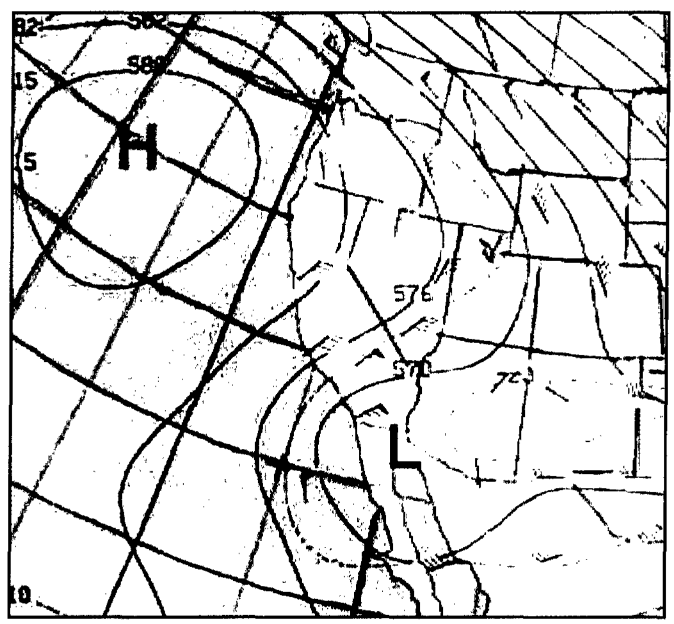

Figure 3-84. 500 mb, 1200Z/27 January 1984

Utah Box

This wind event occurs when long wave troughs exist near the West Coast and a southern storm track is established over the Great Basin region (Figures 3-85 and 3-86).

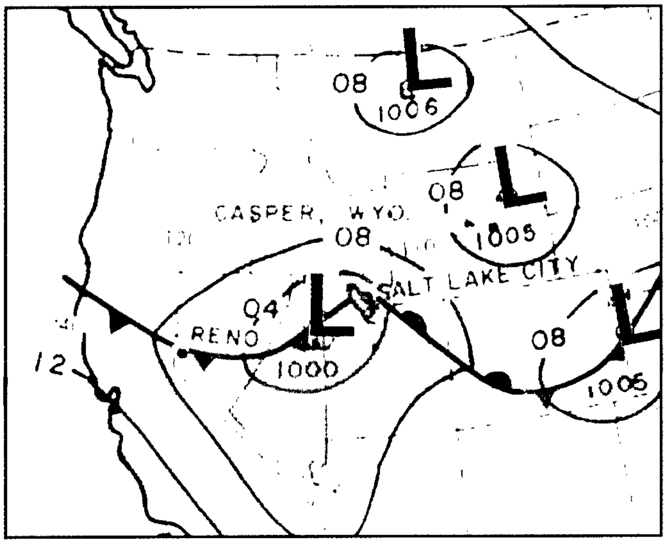

Figure 3-85. Utah Box Surface Example
Strong southerly gradient winds vicinity of frontal wave.

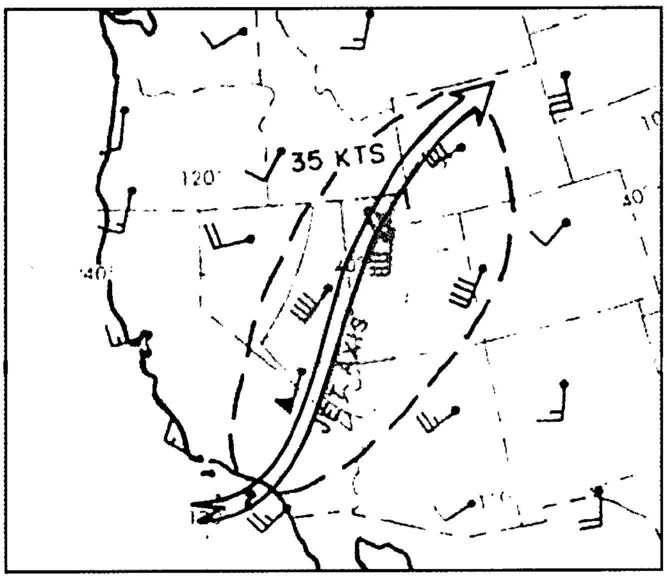

Figure 3-86. Utah Box Mid-Level Maximum Winds
Mid-level jet lies over frontal wave.

Figures 3-87 and 3-88 depict surface and 500 mb analyses favorable for strong southerly winds within the Utah Box (event shown occurred on 14 November 1988).

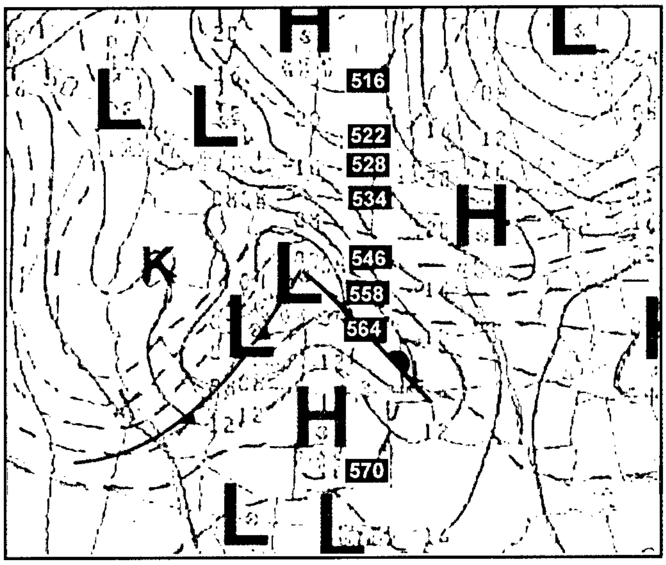

Figure 3-87. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/14 November 1988
Great Basin frontal wave with strong thickness packing over California and Nevada.

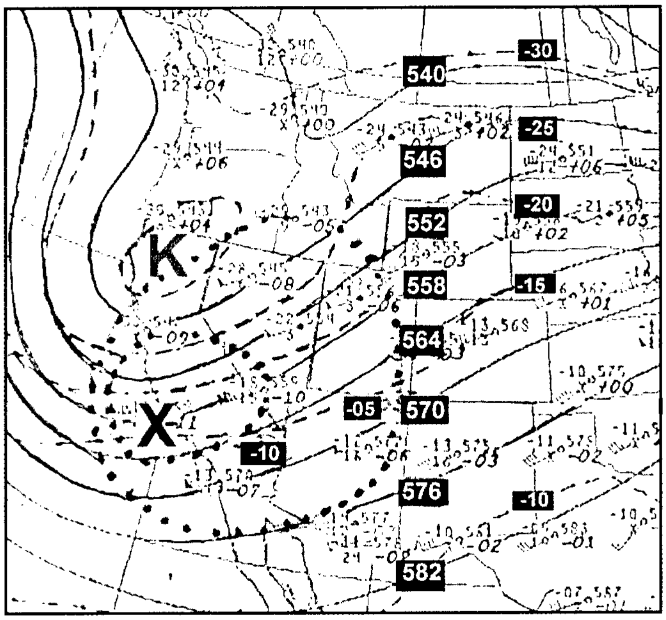

Figure 3-88. 500 mb, 1200Z/14 November 1988
Deepening split-flow trough. Height fall center (**X**) in the vicinity Vandenburg AFB, California

Thunderstorm Regimes

During the winter season, nearly all thunderstorm events are associated with mid and upper-level cold troughs and/or cold pockets (steeper lapse rates) over the western CONUS. Decreasing solar insolation, along with a cold, stable air mass that prevails over the western CONUS limits warm-season type thunderstorm development. One common thunderstorm event is the advection of Pacific Ocean open cell cold air cumulus and low-top cumulonimbus cells that generally affect coastal stations especially in Oregon and Washington. Excluding gradient winds, cold air convection may produce moderate wind gusts (35-45 knots), heavy rain showers and small hail as the cells move inland. Areas of positive vorticity advection are reflected in the appearance of cellular cloud areas or clusters to the rear of cold fronts. The upward motion produces enhanced cumulus. Convection develops within the upper cold trough behind the warmer, baroclinic cloud system (see A in Figure 3-89). Figures 3-89 and 3-90 depict cold air thunderstorm clusters shown by the arrows in both Figures. In Figure 3-89, the cold air convection is some distance from the West Coast. However, the convection could affect coastal stations within 24 hours. In Figure 3-90, cold air thunderstorms (noted by the arrow) continue within the upper low's cold pocket that dropped southward from the Gulf of Alaska. These low-top thunderstorm events gradually subside over land and end west of the Cascade and Sierra Nevada mountain ranges.

The Los Angeles area may experience several severe thunderstorm events (with isolated tornadoes) during mid-winter when low-latitude, strong upper level impulses and their associated ocean convection move onshore.

Figure 3-89. GOES-W IR, 2315Z/ 26 February 1980
Arrow points to cold air cumulus cells. "A" denotes baroclinic clouds, "B" vorticity comma cloud and "C" deformation clouds.

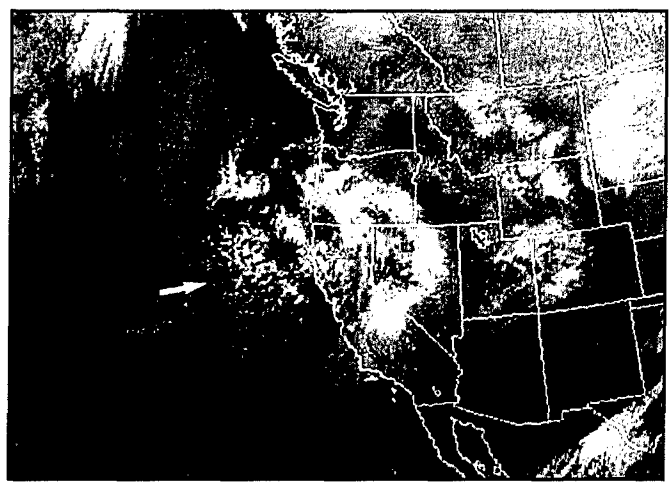

Figure 3-90. GOES-W IR, 1415Z/ 11 February 2001
Cold air cumulus within upper cold pocket appears over northern California and adjacent ocean areas.

Thunderstorms often develop within the cold pockets/thermal troughs of deepening Pacific troughs over the central and southern regions of the western CONUS. These thunderstorms seldom move into the western Great Plains. Most activity dissipates before reaching the Great Plains during the winter season.

Central Conus

All of the information presented so far pertains to analyses, satellite interpretation and empirical rules. Very little model-forecast data has been presented. The intent behind the absence of model guidance is to show that forecaster can produce short-term forecasts on their own by analyzing charts and interpreting satellite data.

Zonal Flow

As presented in the previous chapters, short waves that move through zonal flow occur frequently over the CONUS (Figure 4-1). The associated surface systems produce a variety of winter weather (Figure 4-2).

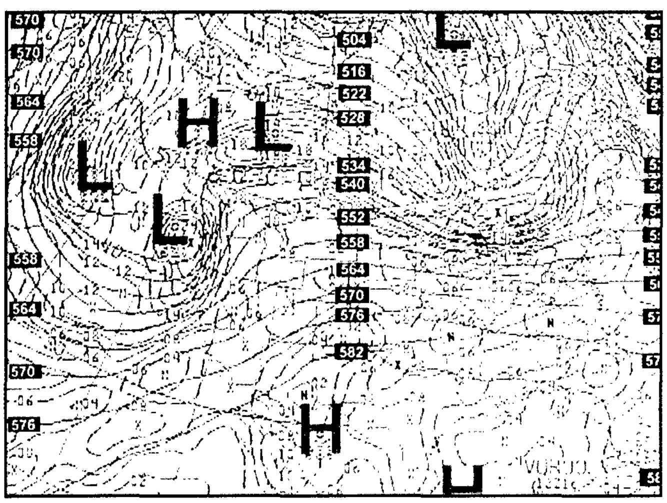

Figure 4-1. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/16 January 2000

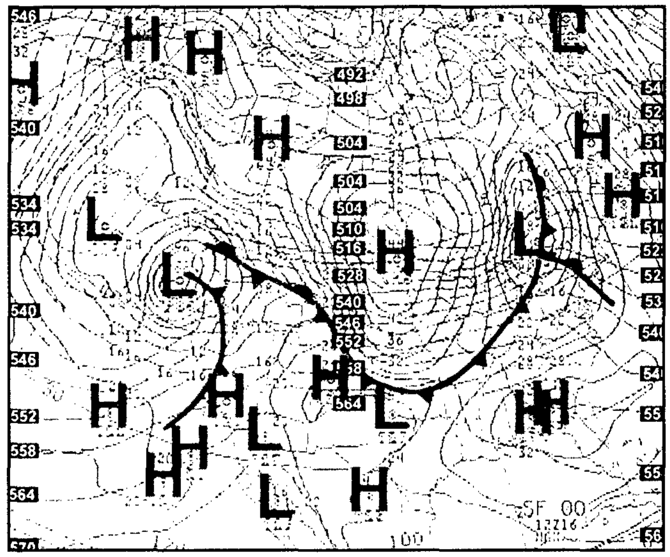

Figure 4-2. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/16 January 2000

Forecasters located over the central CONUS should always be suspicious of approaching Pacific short waves that may undergo deepening west of the Rocky Mountains. A significant storm may evolve over the Western Plains. Early signs of zonal flow deepening on upper air charts are cold air advection, strong polar jet and moderate to strong PVA (and height falls; **X** marks the approximate center) as depicted in Figure 4-3. Height fall centers (HFCs) continuity is excellent in tracking storm movement on conventional charts. The models generally are excellent in predicting trough deepening. Although this event occurred over 20 years ago, it is included to warn forecaster how rapid a storm can develop.

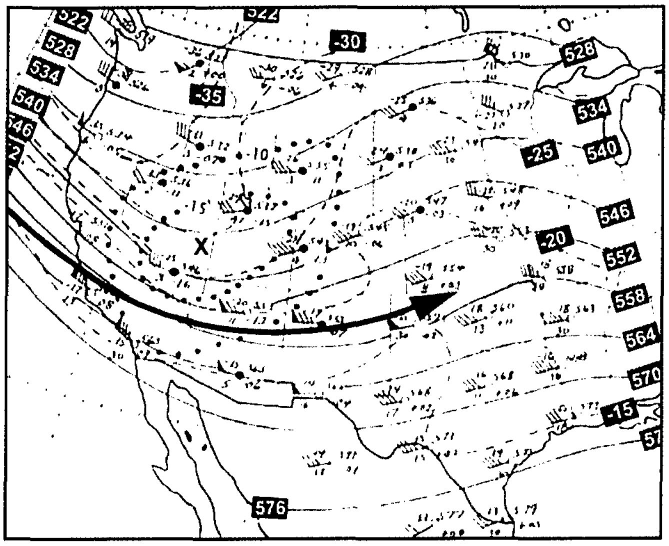

Figure 4-3. 500 mb, 0000Z/9 January 1975
A blizzard occurred within 24 hours over the central and northern Great Plains.

Twelve hours later, Figure 4-4, the trough has deepened as it continues eastward. The contour and thermal gradients have widened over the Idaho-Utah area. The height fall center continues southeastward and is shown over eastern Arizona. A strong jet (90 knots over Tucson) appears at the base of the trough.

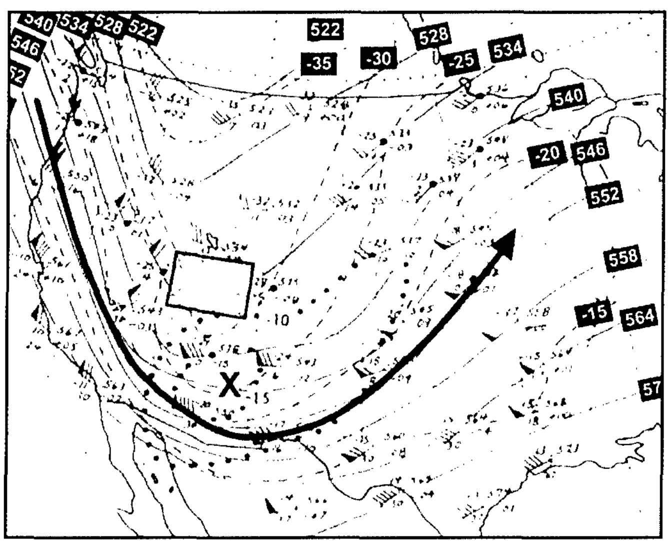

Figure 4-4. 500 mb, 1200Z/9 January 1975
Cyclogenesis should soon develop within the hatched area (see information presented in Chapter 2).

Twelve hours later, Figure 4-5, a closed low appeared over northern New Mexico. The HFC has filled and is gradually turning eastward. During the next 12 hours, the low shown in Figure 4-5 turned abruptly northeastward towards the Central Plains. Figure 4-6 shows the surface conditions related to Figure 4-5. The Texas Low will become the primary low.

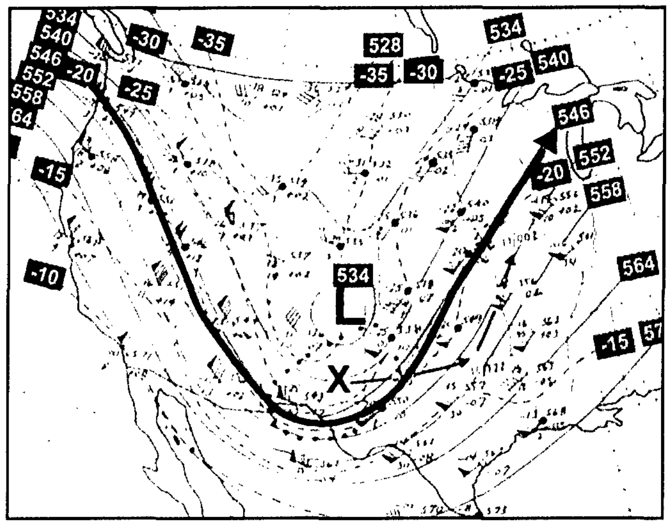

Figure 4-5. 500 mb, 0000Z/10 January 1975
Low has developed and lifted northeastward during the next 12 hours.

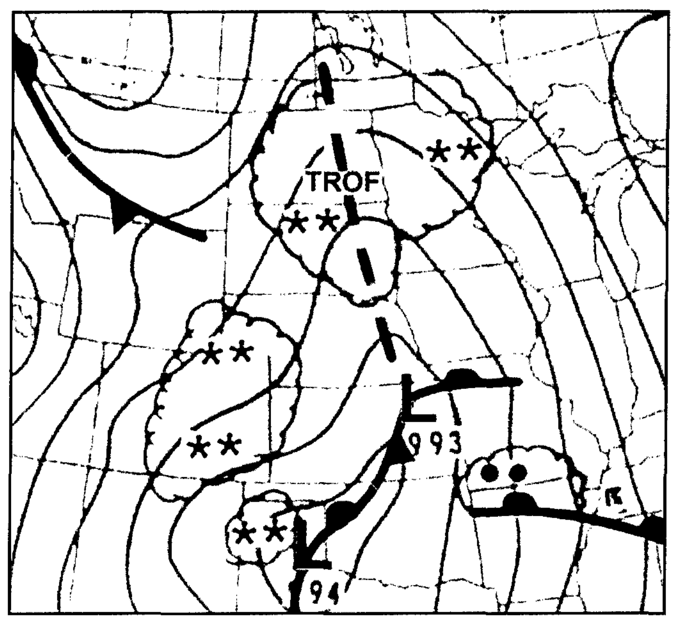

Figure 4-6. Surface, 0000Z/10 January 1975

Figure 4-7 reveals the surface features 30 hours later than Figure 4-6. The storm took a northerly course and deepened rapidly over the Central Plains. The low passed directly over the Omaha, Nebraska area. Forecasters located across the Dakotas eastward to the Great Lakes should watch for recurvature of Great Plains storm systems associated with a receding high. Heavy snowfalls and strong surface winds that may develop blizzard conditions such as shown in Figure 4- 7 occur with deep occluded systems that track northeastward towards the Great Lakes area.

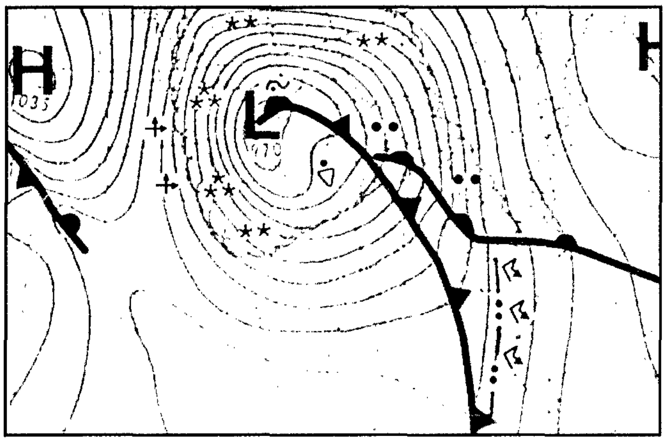

Figure 4-7. Surface, 0600Z/11 January 1975
A blizzard raged across the northern Great Plains.

Meridional Flow

Surges of Canadian polar and arctic air often dominate the central CONUS when the long wave is in place over the Midwest; an example is shown in Figures 4-8 and 4-9. For the Great Plains, this regime produces cold and windy conditions over the northern and central Midwest. Significant precipitation (mainly snowfall), associated with the low-pressure system, affects the Northern Plains and Great Lakes (see low over eastern North Dakota in Figure 4-9).

Upper lows located at the base of a long wave may provide the upper support for Gulf of Mexico frontal low development such as shown in Figures 4-8 and 4-9. In Figure 4-8, a low appears at the base of the long wave over Mexico; in Figure 4-9, the related surface low is shown southeast of Brownsville, Texas (noted by the arrow). Frontal lows in the Gulf of Mexico may evolve into intense Atlantic coastal storms (Nor'easters) that produce strong winds, significant snowfall and freezing rain in the interior areas of the eastern CONUS. More information on this regime will be presented in the next chapter.

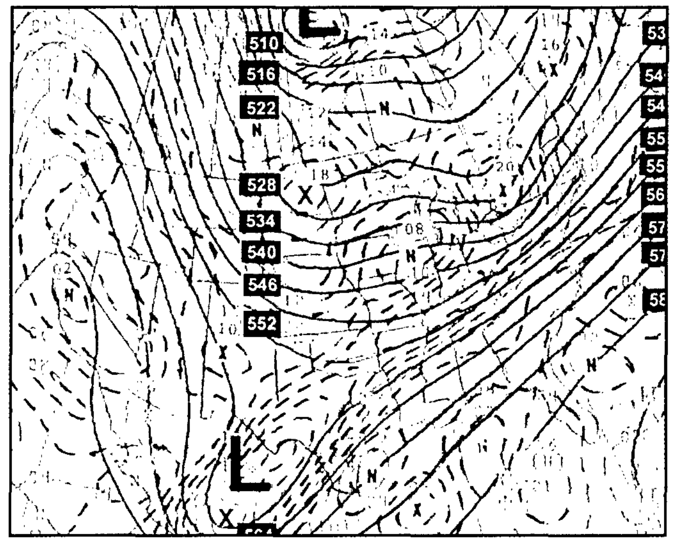

Figure 4-8. 00HR 500 mb Heights/Vorticity, 1200Z/21 January 1987
Long wave trough located over the central CONUS.

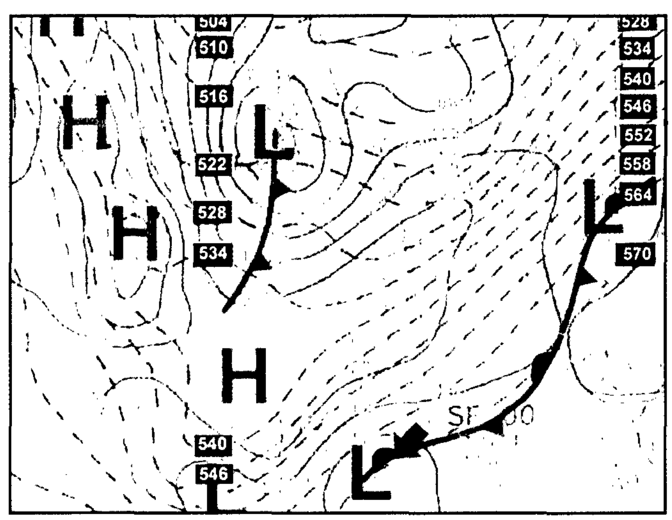

Figure 4-9. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/21 January 1987
Low dropping southward over the Northern Plains.

Anticyclonic Regimes

Two anticyclonic regimes that appear routinely on surface and model charts are presented at this time (excluding the Great Basin High). It is important for forecasters to recognize which of these two regimes will exist when a storm system is developing and moving toward their locations. Of course, there will be many variations to these two basic regimes. These two regimes will be mentioned throughout the remainder of this Technical Note.

Receding High

Figure 4-10 depicts a receding high-pressure example across the central and eastern CONUS. Migratory cP highs from Canada or highs that have crossed the Rocky Mountains modify and move eastward across the eastern CONUS towards the Atlantic Ocean. Return southerly flow advects warmer more moist air northward ahead of the next developing disturbance. Often, there is an absence of significant precipitation over the Great Plains during the early stage. Clouds and precipitation develop rapidly when Gulf moisture advects northward and interacts with an upper-level impulse that has moved into the Western Plains. This regime is often observed with zonal flow or short waves independent of long wave troughs.

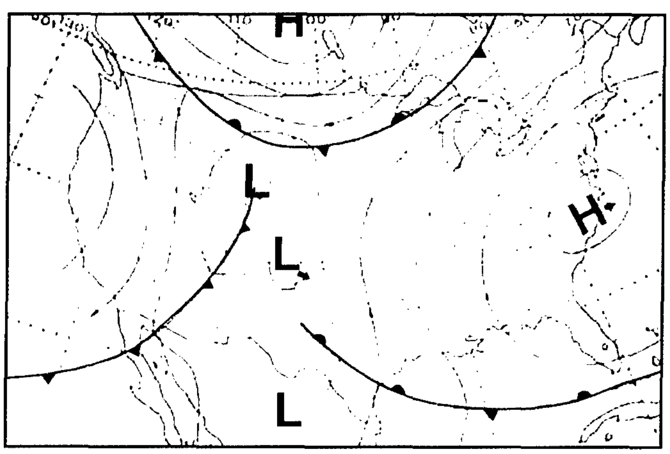

Figure 4-10. Receding High Example 1

A second receding high example is shown in Figure 4-11. The surface condition shown often evolves into a major storm system when the upper support arrives over the western Great Plains. Warm frontogenesis may occur over the Central Plains as increased warm air and Gulf moisture advection meets cold polar air over the Northern Plains (Figure 4-11). Overrunning precipitation breaks out along and north of the warm front. Often a cP front drops southward to the rear of the surface low and provides the cold air for further storm development.

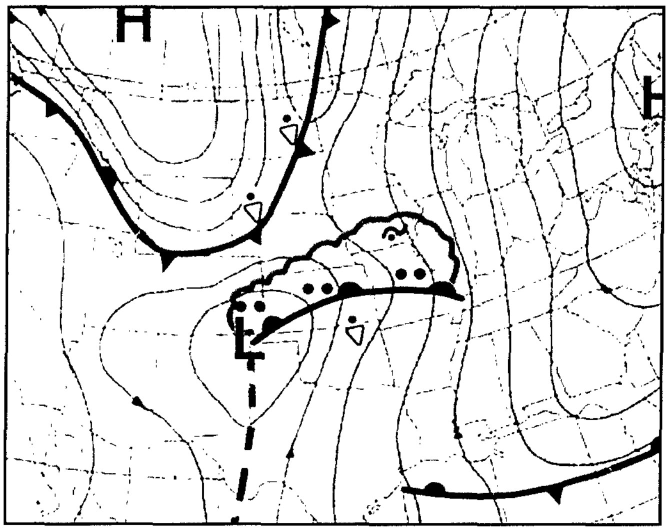

Figure 4-11. Receding High Example 2

Prevailing High

In Figure 4- 12, a persistent ridge of cold polar air extends east-west across the central and northern CONUS. The jet stream and primary storm tracks are located across the southern states. Gulf moisture advects northward over the shallow cold dome; widespread overrunning precipitation gradually develops within the colder easterly flow and becomes extensive when frontal disturbances intensify. Frontal cyclogenesis occurs over the southern Rockies as the upper support approaches (Albuquerque low). This regime is often observed with large-scale meridional trough systems located over the central CONUS. A variety of precipitation types generally occur over large areas of the southern CONUS as shown in Figure 4-12.

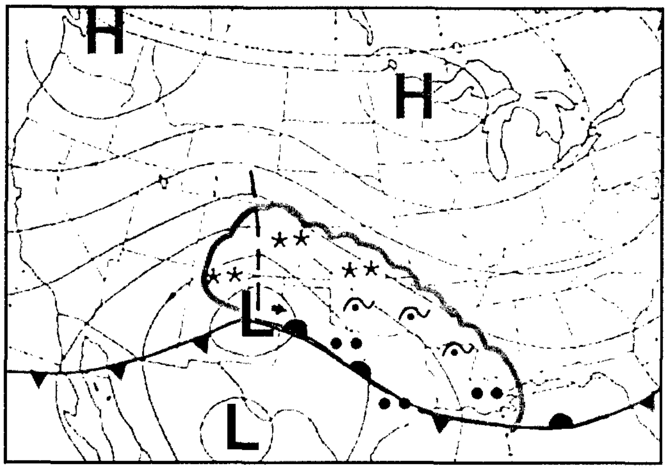

Figure 4-12. Prevailing High
Most of the nation is under polar air masses. Storms track across the southern CONUS.

Cloud Regimes (Prevailing and Receding Highs)

During the months of October through May, and more particularly from December through March, dense fog, thunderstorms, heavy rains, paralyzing snowstorms, and/or freezing precipitation have encompassed large portions of the central and eastern CONUS. The prospects of such a storm coming out of the Rocky Mountains and joining up with all the needed ingredients to make its presence felt and long remembered greatly concerns forecasters throughout the central CONUS. An essential asset for these forecasters is the ability to identify the source of moisture and then to determine the rate of movement and extent of the moisture contributed to the storm system. It is a well-established fact that the basic moisture source region turns out to be the western Gulf of Mexico in nearly every case. The problem lies in determining how much moisture will become available and over what area the moist air will be advected. Thus, in this section are presented the surface pressure patterns and low-level flow most favorable for the advection of Gulf moisture into the nation's midsection. As it is essential to the spread of moisture well inland of the Texas coast, the low-level jet (LLJ) – its identification, formation and role – is also presented. Gulf moisture can spread rapidly northward within 24 hours and interact with a Rocky Mountain storm system that results in widespread winter weather over the central and eastern CONUS as was shown in the cover illustration.

There are two distinct moisture regimes over Texas that possess different characteristics and are the result of certain surface and upper-air features. They are residual moisture (prevailing high) and open flow Gulf moisture. One of these two regimes will usually develop or exist ahead of a cold frontal system and/or low- pressure system approaching the central CONUS from the Rocky Mountains.

Cloud Systems - Prevailing High

Large stagnant polar air masses (prevailing high) produce extensive areas of low ceilings, fog and precipitation (mostly overrunning) across large areas from the Rocky Mountains to the East Coast. Often, post frontal stratus (residual stratus) stagnates over Texas as the front becomes stationary. Also, upslope cloud systems develop over the western Great Plains and spread eastward as Gulf moisture overruns the shallow air mass. These synoptic regimes may persist for several days and, perhaps, for a week before the pattern changes (Figures 4-13 and 4-14). Forecasters should not be in a hurry to forecast a break in this persistent, cold, drab regime. Often, upper-level features show little eastward movement (in many cases, a stationary cold core trough is located off the East Coast). Several examples will now be shown.

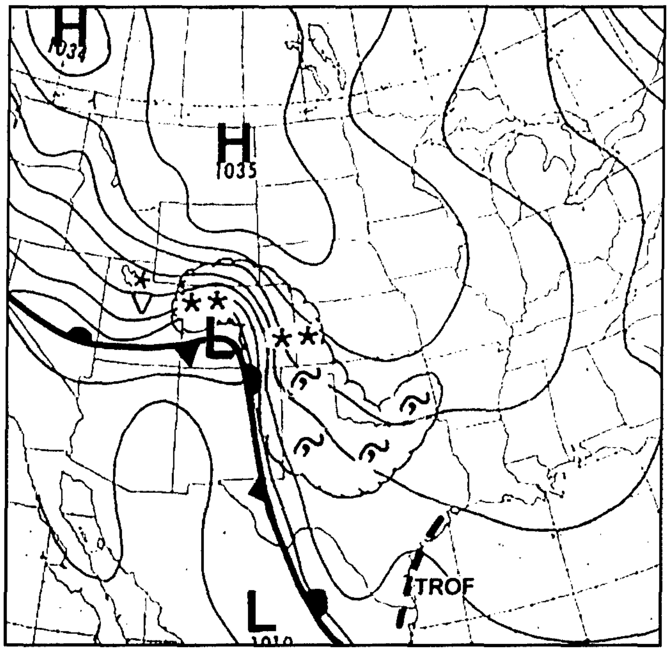

Figure 4-13. Surface, 1800Z/28 January 1980
High pressure prevails. Upslope freezing drizzle. See related GOES imagery in Figure 4-15.

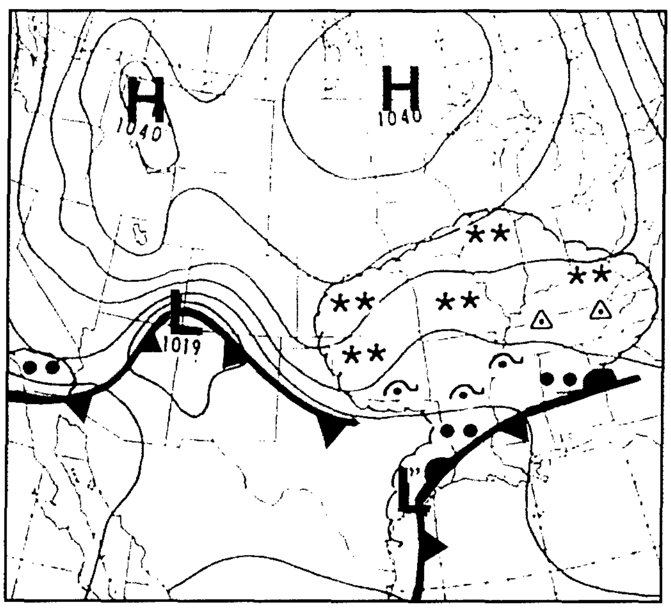

Figure 4-14. Surface, 1800Z/30 January 1980
Two days later than Figure 4-13. Widespread overrunning and precipitation. See GOES imagery in Figure 4-16.

In the satellite images shown in Figures 4- 15 and 4- 16 (related to Figures 4-13 and 4- 14), an extensive area of stratus is shown from Mexico northward into the central Midwest. The overall cloud pattern did not change significantly although the pictures are approximately 45 hours apart. The stratus pattern usually begins when upslope stratus appears east of the Rockies in New Mexico, Colorado and Wyoming and western Kansas, Oklahoma and the Texas Panhandle, as cold moves southward. Later, as the polar ridge shifts slowly eastward (Figure 4-14), the low-level winds across Texas become southeasterly and advects Gulf moisture northward. In time, northward advection of this moisture merges with the already existing upslope stratus and establishes the cloud patterns shown in Figures 4-15 and 4-16. Overrunning precipitation develops and spreads eastward. Generally, rain occurs along and behind the polar front; snow and freezing precipitation extends northward into the western Central Plains. Precipitation increases significantly when cyclogenesis develops along the polar front.

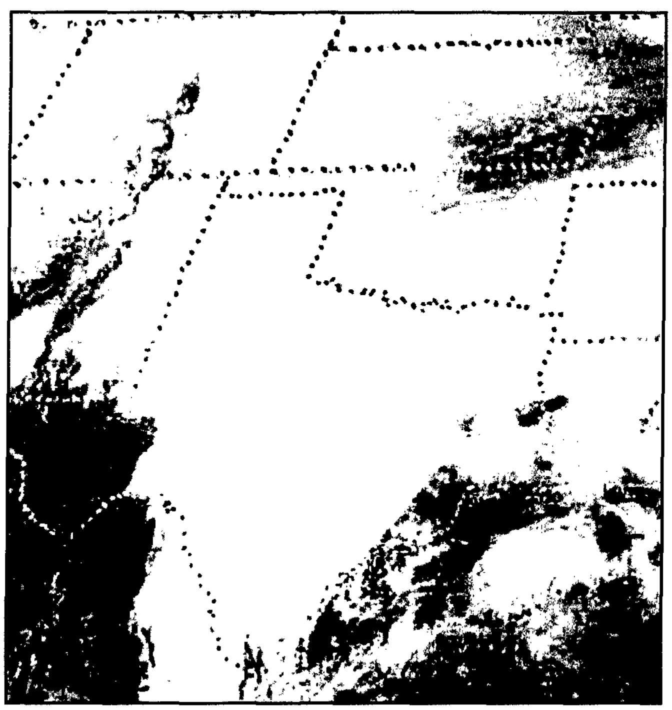

Figure 4-15. GOES-E VIS, 1916Z/ 28 January 1980

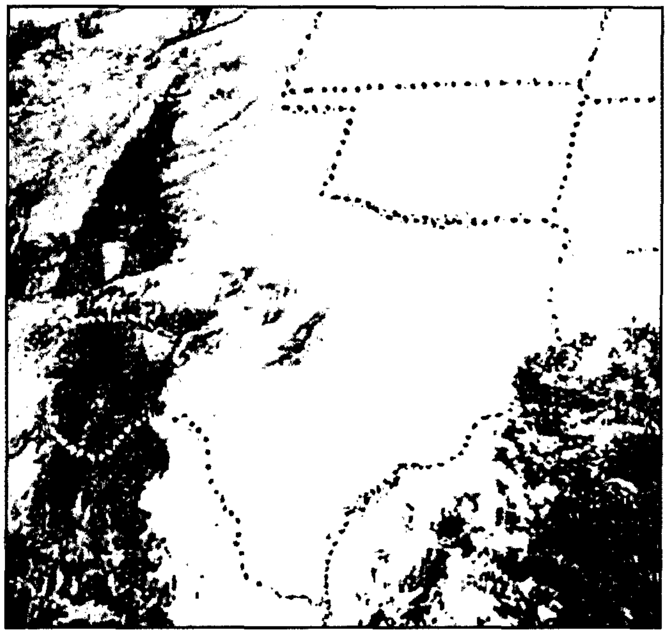

Figure 4-16. GOES-E VIS, 1646Z/ 30 January 1980
Two days later than Figure 4-15.

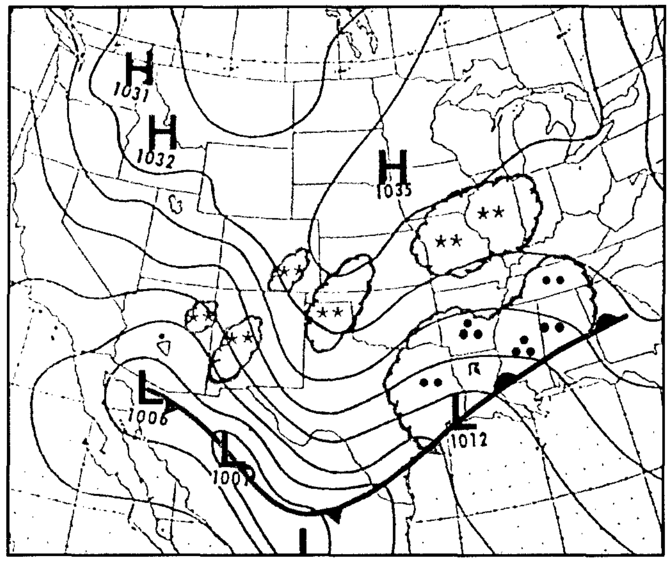

Figure 4-17. Prevailing High, 8 February 1980
Stationary front along Gulf Coast. Strong overrunning of the polar air mass.

To forecast ceiling and precipitation improvement, forecasters must watch for an upper-level impulse (pressure and thermal troughs, PVA, etc.) approaching the Rockies which will initiate cyclogenesis along the polar front. This is illustrated in the following figure sequence that is not related to the previous event shown in Figures 4-15 and 4-16.

Figure 4-17 depicts a prevailing high-pressure regime. The cloud pattern shown in the satellite image (Figure 4-18) over the Southern Plains closely resembles the satellite images shown earlier in Figures 4-15 and 4-16. In the satellite image, Figure 4-18, a short wave appears over southern Arizona and New Mexico as indicated by the arrow. The 1200Z 500 mb analysis, (see inset in Figure 4-18; 11 hours earlier than Figure 4-18), confirms the short wave position; this feature is the trigger for intensification of the polar frontal low over southeastern Texas. Twenty-four hours later, the wave traveled along the Gulf Coast; the persistent stratus condition over Texas and northward cleared as the high over the upper Midwest plunged southward bringing drier air into the region.

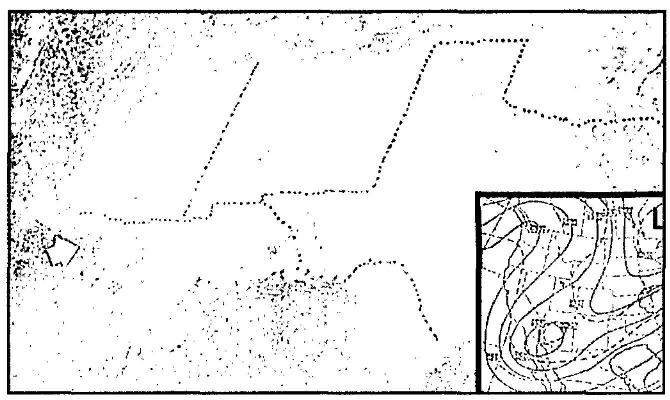

Figure 4-18. Synchronous Meteorological Satellite (SMS-2) VIS, 2246Z/8 February 1980
Extensive cloud system associated with a long wave trough regime. Inset shows short wave split-flow low appears within the base of the long wave (arrow).

Cloud Systems - Receding High

Northward moisture advection from the Gulf of Mexico occurs often when high-pressure systems move into the eastern CONUS. This moisture regime is often identified as Gulf Moisture Advection. Gulf stratus formation and/or advection occurs frequently over Texas when warm southerly low-level winds return over the region.

Gulf stratus is defined as a stratus and/or stratocumulus layer progressing into the coastal areas of Mexico, Texas and Louisiana from the Gulf of Mexico generally below 5,000 feet. Gulf stratus can occur anywhere along the Gulf Coast depending on the synoptic pattern, but occurs most frequently over Texas. Stratus formation over the rising terrain of south central Texas (usually in the San Antonio, Austin, and Junction area) is also considered for initial stratus advection. There is some dissimilarity between it and prevailing high stratus (residual stratus). The most distinguishable difference is the surface pressure pattern. Figure 4-19 depicts a typical surface pattern during the initial phase of Gulf stratus advection in conjunction with a deepening storm system over the Rocky Mountains. The surface and low-level flow from the Gulf of Mexico to the Central Plains has a continuous open southerly flow and is not interrupted by any significant east-west frontal or trough systems. Weak warm fronts (often appearing as a result of warmer Gulf flow) may develop, but are not strong enough to disrupt the southerly flow. Gulf stratus advection will sometimes overrun an east-west frontal/trough system over the northern Midwest region; low ceilings and fog and drizzle (often freezing drizzle) develop within the colder air mass. The upslope stratus and precipitation shown in Figure 4-19 is not associated with the Gulf stratus advection.

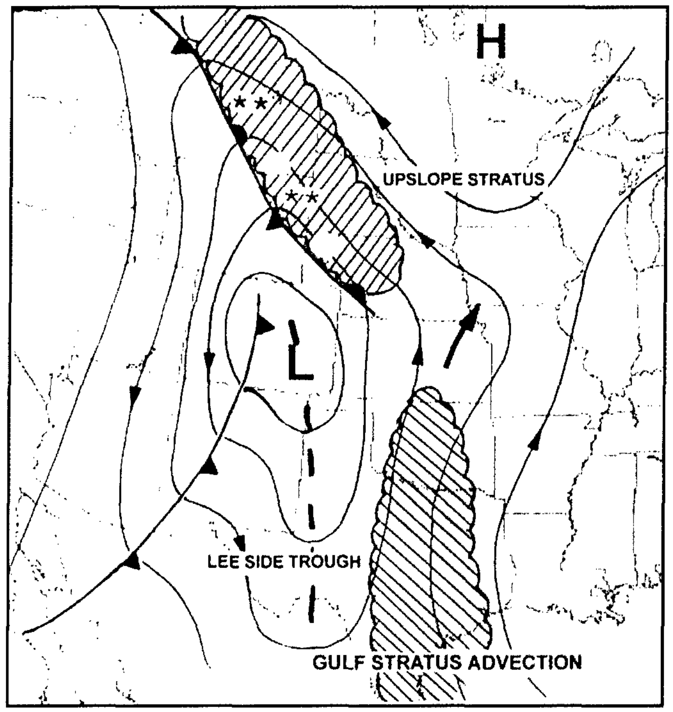

Figure 4-19. Gulf Stratus Advection Model

The stratus layer shown off the coast of Mexico in Figure 4-20 often will move inland and move northward into southern Texas when the low-level winds return to a southerly component. Upslope stratus often develops over eastern Mexico as Gulf moisture moves inland within an easterly low-level flow.

Figure 4-20. GOES-E VIS, 1545Z/ 4 February 1999
Stratus/stratocumulus over the Gulf of Mexico.

Gulf stratus generally advects northward as an identifiable cloud system as shown in the following figures. Stratus advection > 5,000 feet (scalloped area) can be tracked on cloud analysis charts as shown in Figure 4-21 or on surface observations. The visible satellite images, Figures 4-22 and 4-23, reveal two separate moisture advection tongues over Texas. Advection track usually follows an anticyclonic path on the backside of receding highs.

Ceiling heights during initial advection vary and are dependent on the strength of the low-level wind flow, the local terrain and time of day. Average ceiling heights are near 2,500 feet along the main track. The average top of Gulf stratus advection is generally at or below 5,000 feet during the early stages. Often, the 850 mb wind direction is from a southwest component along the expected stratus track and may lead forecasters to think that the stratus will miss their area. (Wind direction below 850 mb back to a southerly direction and allows stratus to advect northward even though the 850 mb wind is southwesterly). Once under the influence of a frontal zone, the Gulf moisture in the air mass becomes unstable and rapid building into the higher levels occurs.

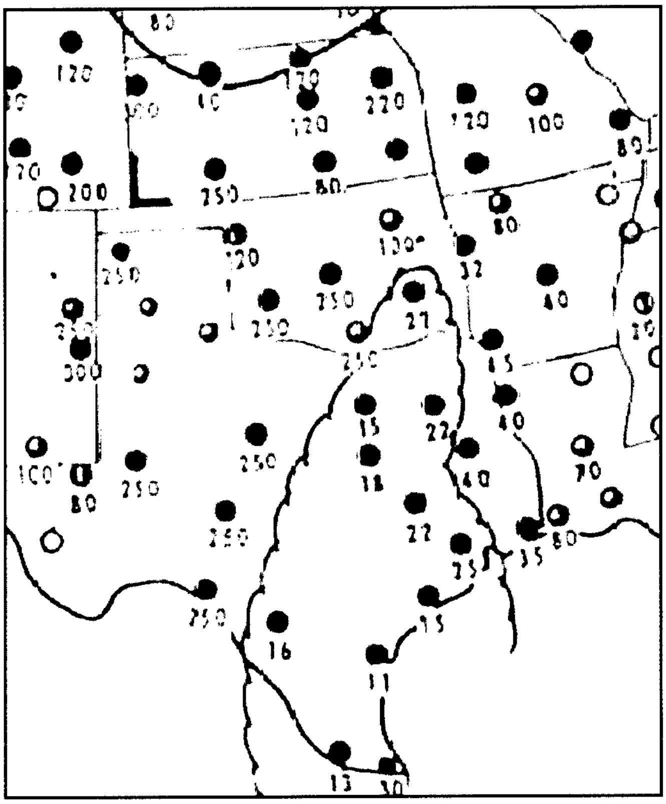

Figure 4-21. Nephanalysis, 4 January 1978
Scalloped area defines Gulf stratus (tops =5000 ft).

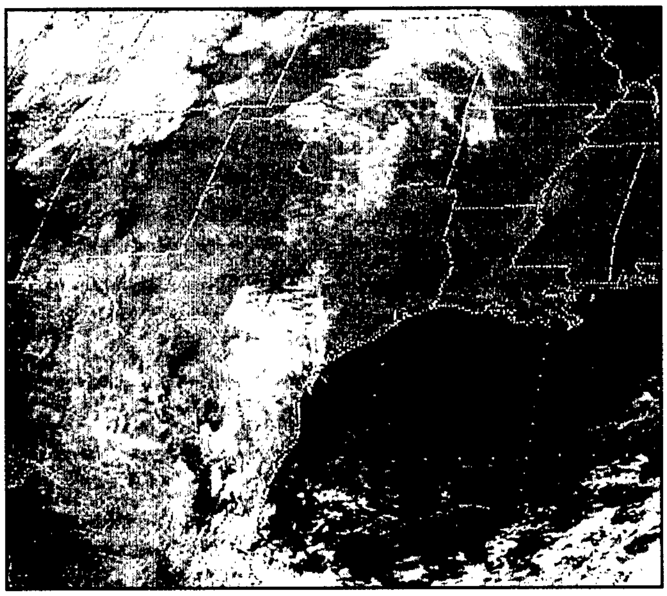

Figure 4-22. GOES-E VIS, 1630Z/ 25 February 1984
Gulf moisture advection over southern Texas.

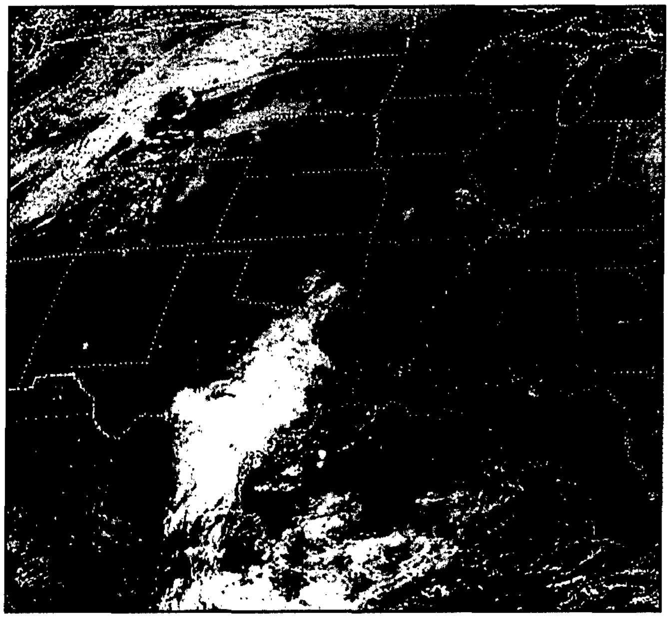

Figure 4-23. GOES-E VIS, 1918Z/ 10 December 1979
Stratus advected into the Upper Mississippi Valley.

Occasionally during the winter season, advection fog will develop over areas of Texas, Louisiana and Oklahoma under a weak return flow of a strong cP ridge that has persisted over the Midwest. The formation of advection fog, coupled with radiational cooling, will advance slowly northward. Normally, dissipation would be expected during the daylight hours, however, advection fog under a persistent strong ridge will be sustained throughout the period. Ceiling heights along the leading edge of advection fog are very low and usually lower to W0X0F (zero ceiling and zero visibility) conditions within a few hours. This condition is not considered Gulf stratus advection; the pressure pattern and the absence of low-level jet activity favor a residual (prevailing high) pattern.

Low-Level Jet and Gulf Moisture Advection

The existence of low-level jets over the Great Plains is well known. They are characterized by significant maxima of wind, most often below 5,000 feet, and usually occur at night. A study of winds aloft data years ago indicates that maximum winds occur between 0600Z and 1200Z and at an altitude of 3,000 to 4,000 feet. During the day, the jet weakens (jet descends to the surface due to heating). It can, however, persist for longer periods, especially preceding a strong cold front or during periods of minimum surface heating. It has been found that Gulf stratus advects into the Midwest at approximately 100% of the 3,000-4,000 foot flow; the mean stratus layer is also normally located within this layer. Boundary layer products would not identify this maximum wind layer since maximum winds occur above 2,000 feet. Doppler radar wind products and wind profilers located over the Great Plains would reveal these maximum wind speed layers

Figure 4-24 shows a typical synoptic setup for stratus advection. Low-level jets develop east of the lee-side trough. Normally, a maritime polar cold

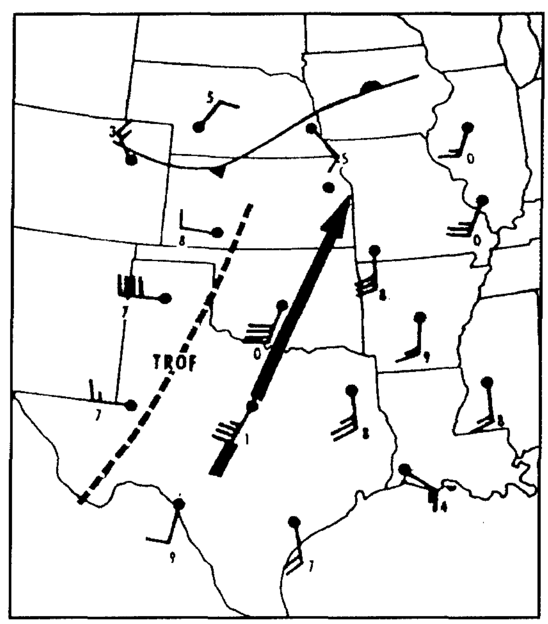

Figure 4-24. Low-Level Jet Formation Model

front is approaching from the west and will "drop" into the lee-side trough (see Figure 4-19). Gulf stratus usually encounters the frontal system over central Oklahoma and Kansas.

Figure 4-25 is a vertical wind profile of low-level jet activity over the Oklahoma City (OKC sounding) region a few years ago. The wind speed increased from 30 knots to 60 knots at 4,000 feet. The slight decrease in wind speed at 7,000 feet probably is the defining layer between the top of the low-level jet and the bottom of the mid-level jet. Figure 4-26 (not related to Figure 4-25) shows wind profiler data during the morning hours over Conway, Missouri that is located in southern Missouri (see map in Figure 4-27). In Figure 4-26, the dark arrow points to the low-level jet—max wind speeds shown are 55 knots.

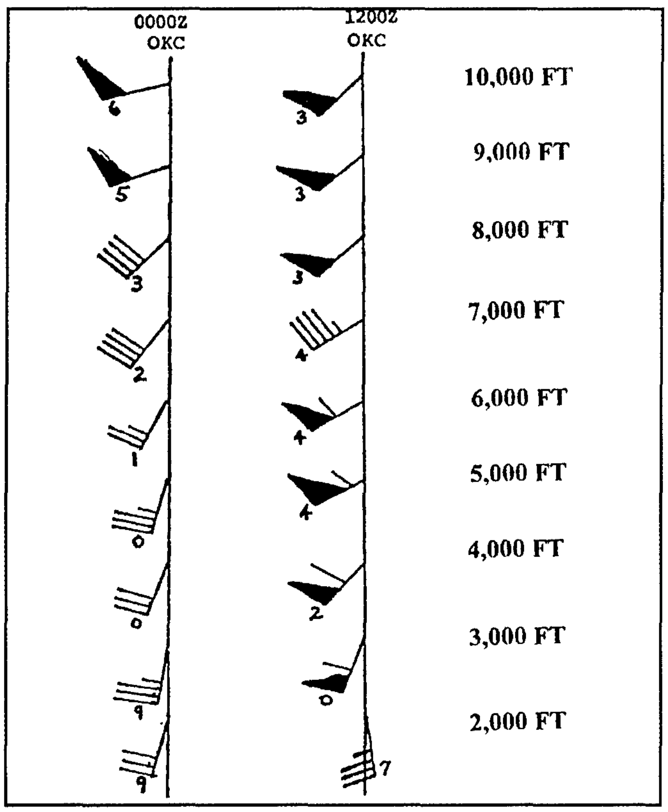

Figure 4-25. Vertical Wind Profile from Oklahoma City RAOB, Early March

Notice that the wind speed decreases above 2.8 km (9,000 feet) and then increases above 3.2 km. Vertical wind profiles can also be obtained from the WSR-88D Doppler radar vertical wind profile (VWP) product (see Figure 4-28).

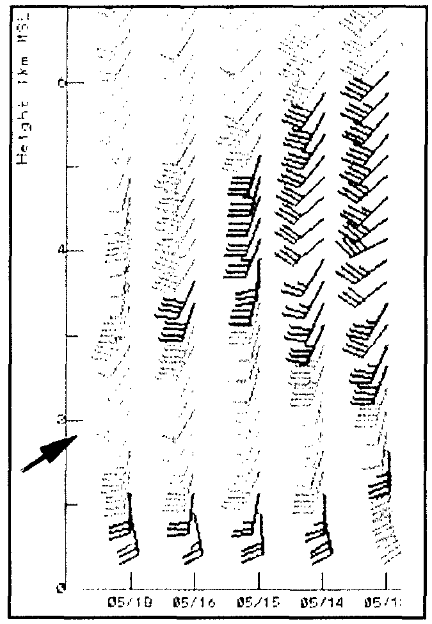

Figure 4-26. Wind Profile - Conway, Missouri, 5 May 1999

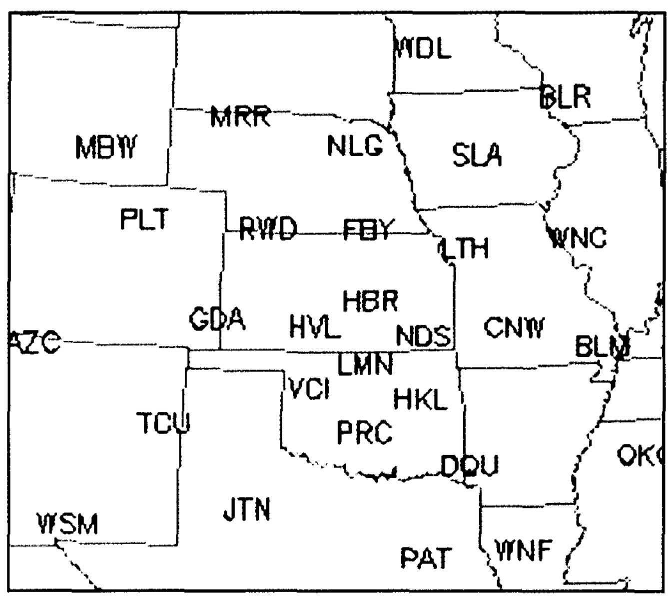

Figure 4-27. Wind Profilers
CNW is location of Conway, Missouri wind profiler.

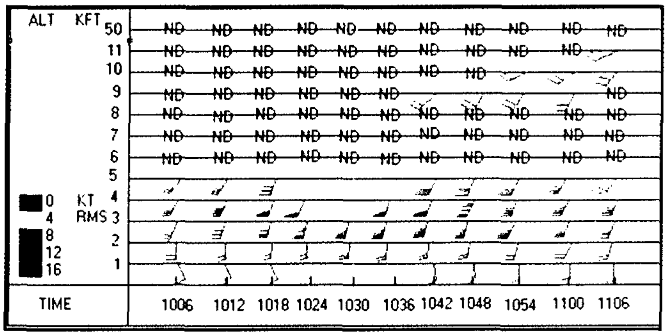

Figure 4-28. WSR 88-D VWP, Ft Worth, Texas, 7 December 1997

Note the LLJ strengthening just before sunrise. This is typical and is the most likely time aircraft will experience low-level wind shear (LLWS).

Forecasting the strength of the low-level jet maximum wind speeds is difficult using analysis data. Numerical model forecast products are helpful. An empirical method for forecasting the maximum strength of the nocturnal low-level jet was developed from four years of data over the central and southern Great Plains many years ago. Figure 4-29 gives the relationship of the 0000Z Amarillo (AMA) and Ft. Worth-Dallas (FWD) 850 mb gradient and the forecast 0600Z low-level maximum winds over Oklahoma City (OKC) which would be representative all along the jet stream corridor. The method is usable within a south to north flow (no frontal/trough intrusions to disrupt the gradient).

850 MB

GRADIENT/SPEED RELATIONSHIP

AMA – FWD

Initial 0000Z *Dm (METERS)*	**Fcst 0600Z** *JET SPEEDS*
45 — 60	30 — 40K
60 — 75	40 — 50K
75 — 90	50 — 60K
≥ 90	> 60K

Figure 4-29. 850 mb Gradient/Speed Relationship

Figures 4-30a through 4-30d depict an ideal pattern for Gulf stratus advection (drawn from case studies). The low-level jet appeared over western Kansas at 0600Z (Figure 4-30a) and shifted eastward and strengthened considerably at 1800Z (Figure 4-30c). Normally, the jet would not be this strong at 1800Z (60-70 knots), but probably persisted due to the strong pressure gradient (AMA-FWD 850 mb 100 meters gradient) at 1200Z (Figure 4-30b). The AMA-FWD 850 mb gradient decreased to 76 meters by 0000Z (Figure 4-30d). The hatched area shown in the figures represents Gulf moisture advection (Gulf stratus) = 5,000 feet at the valid time of the chart.

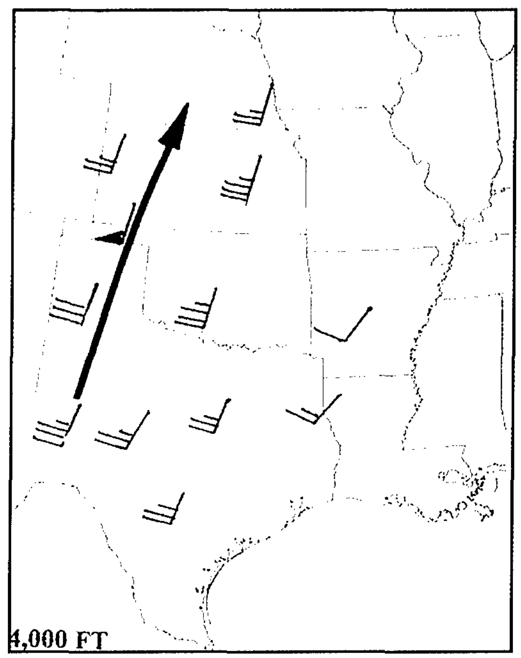

Figure 4-30a. Ideal Gulf Stratus Advection Case - 0600Z

Low-level jet has developed over the Western Plains.

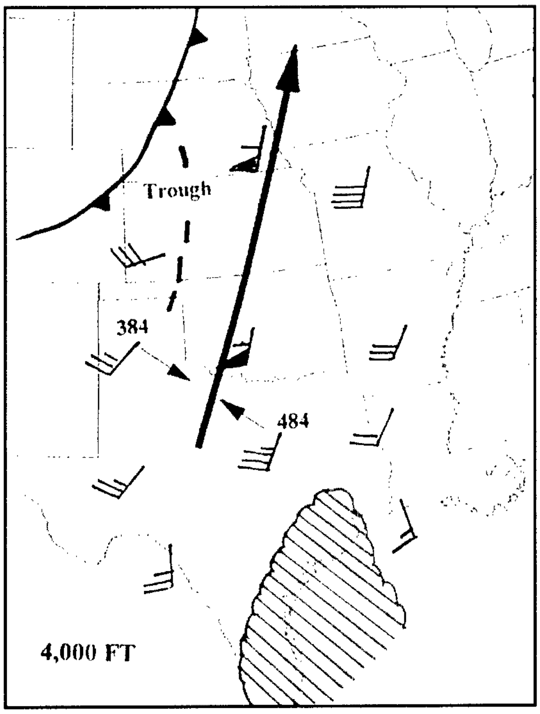

Figure 4-30b. Ideal Gulf Stratus Advection Case - 1200Z
Wind speeds increased as the LLJ shifts eastward. Gulf moisture has arrived.

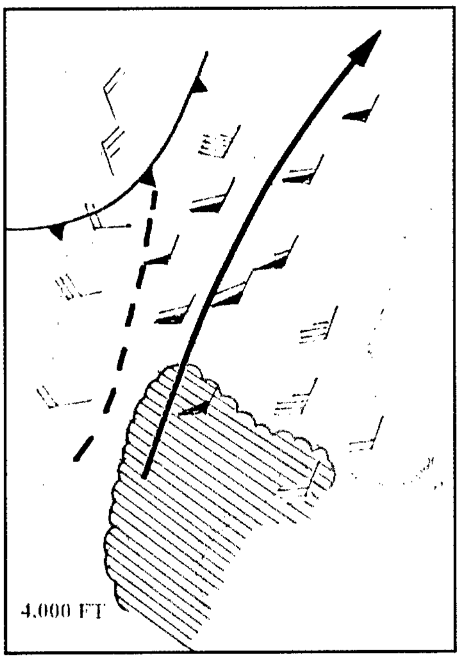

Figure 4-30c. Ideal Gulf Stratus Advection Case - 1800Z
Strong low-level jet across the Central Plains. Gulf moisture has advected into northern Texas.

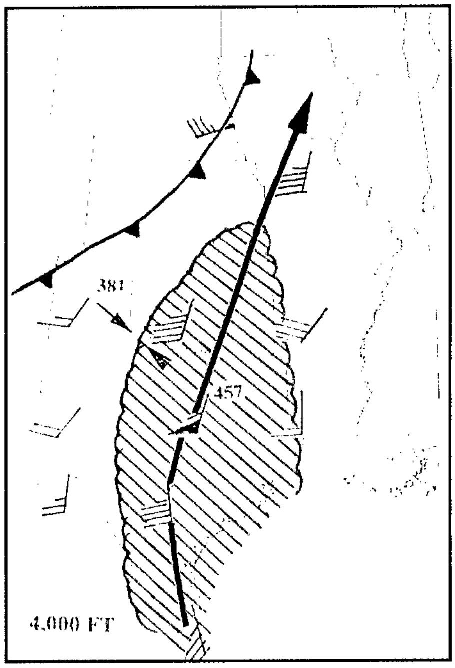

Figure 4-30d. Ideal Gulf Stratus Advection Case - 0000Z
Jet strength has weakened as winds worked to the surface due to surface heating. Gulf moisture has advected into southeast Kansas.

Gulf Stratus Advection Tracks

Stratus enters Texas from the Gulf along various tracks, but for practical use, three main tracks (or Types) have been identified:

- Type 1 - Formation is in eastern Mexico with stratus advection into western Texas and northward.
- Type 2 -Stratus advects inland along the Texas Gulf Coast and spreads northward.
- Type 3 - Development over south-central Texas with rapid advection into the Central Plains.

Figures 4-31 through 4-46 depict primary and some secondary tracks of Gulf stratus advection through Texas into the Central Plains. One of these three-advection tracks is likely to occur when high pressure shifts eastward far enough to return southerly flow to Texas. In all cases, there was no precipitation associated with Gulf stratus (except drizzle through southern Texas). The main body of the stratus cloud area lies to the right and is parallel to the low-level jet axis. Subsequent precipitation will likely develop over the Great Plains after stratus has persisted and interacts with frontal systems that has emerged from the Rocky Mountains.

Type 1 Gulf Stratus

The orientation of high-pressure system's ridge axes (northeast southwest) through the eastern CONUS prevents long trajectories over the northern sections of the Gulf. Consequently, the low-level flow is from the northeast that advects dry air into eastern Texas. At the same time, a longer trajectory is established through the central and southern sections of the Gulf. With a longer trajectory over water, moist air moves into the coastal areas of eastern Mexico and stratus advects northwesterly, east of the Sierra Madre Oriental Mountains of eastern Mexico (Figure 4-31). Laredo and Laughlin AFB are the first reporting stations in Texas to be affected. Stratus advects rapidly northward and is induced into the low-level jet that is present through western Texas, Oklahoma and Kansas. Stratus continues to advect into central Kansas, curving northeasterly into Nebraska along the primary track. Figures 4-32 and 4-33 illustrate two Type 1 events.

Figure 4-31. Type 1 Gulf Stratus Advection Tracks and LLJ Position

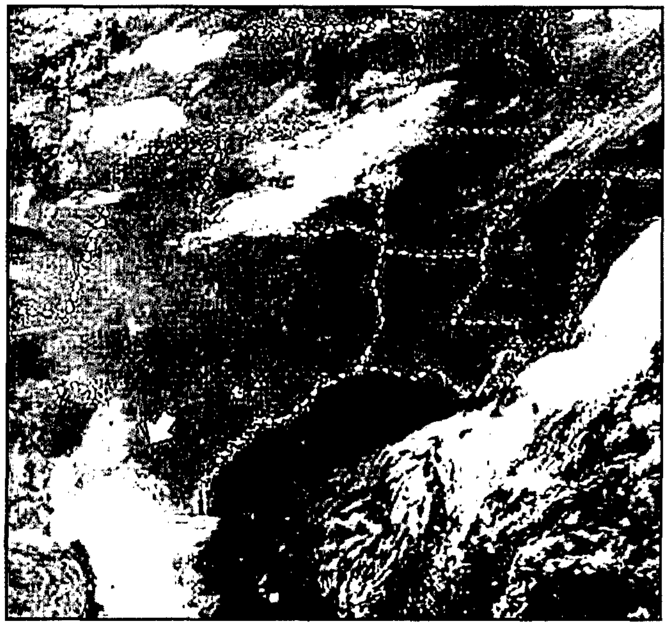

Figure 4-32. GOES-E VIS, 1816Z/ 2 November 1979
Type 1 Gulf stratus from Mexico has advected into southwest Texas.

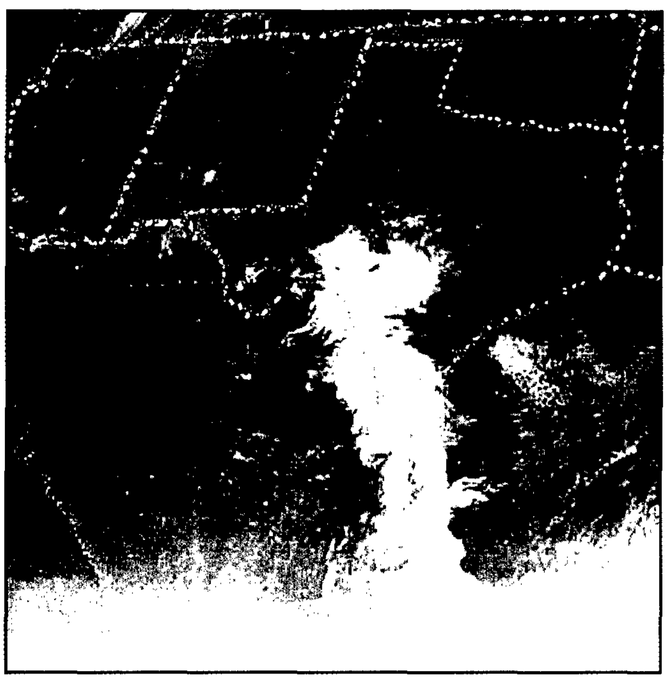

Figure 4-33. GOES-E VIS, 2036Z/ 12 November 1981
Type 1 Gulf stratus advected northward over eastern Mexico (east of the mountains) into southern Texas.

An excellent example of Type 1 stratus advection occurred on January 25, 2001 while finalizing this Technical Note (Figures 4-34 through 4-40). Figures 4-34 and 4-35 (same valid time) depict Type 1 stratus advection from the Gulf of Mexico to the western Great Plains. Figure 4-35 is a color version of Figure 4-34: yellow image represents low clouds; dark blue shows higher clouds.

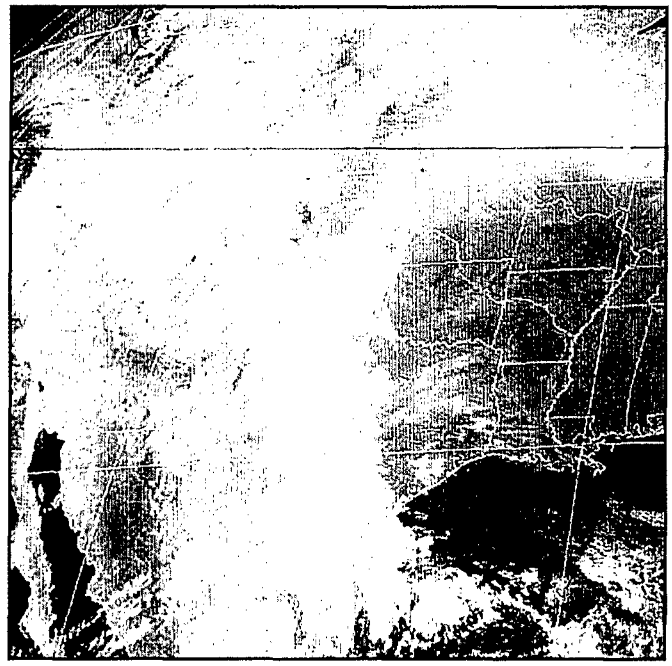

Figure 4-34. GOES-E VIS, 1745Z/ 25 January 2001
Stratus advection from the Gulf of Mexico to the western High Plains.

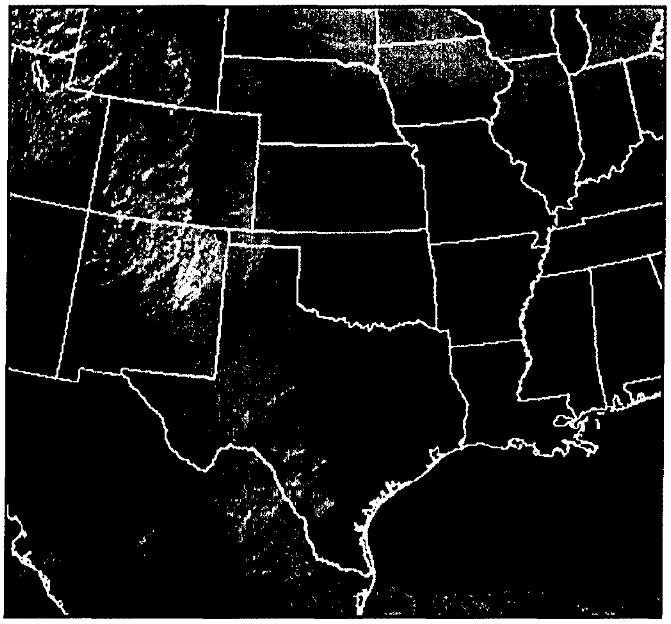

Figure 4-35. GOES-E VIS (Fog Product), 1745Z/ 25 January 2001

Figure 4-36 focuses in on Gulf stratus advection over western Texas and eastern New Mexico (30 minutes later than Figure 4-34). A stream of moist Gulf air can be seen over western Texas.

Figure 4-36. GOES-E VIS, 1815Z/ 25 February 2001

The surface analysis is shown in Figure 4-37. The location of the high-pressure center is too far west to allow for Gulf stratus advection into eastern Texas. Drier continental air from the high continues across the northern Gulf (noted by the drier air arrow). Meanwhile, moist air over a longer trajectory across the southern Gulf, has advected northward over eastern Mexico (east of the mountains) is indicated by the moist air arrow.

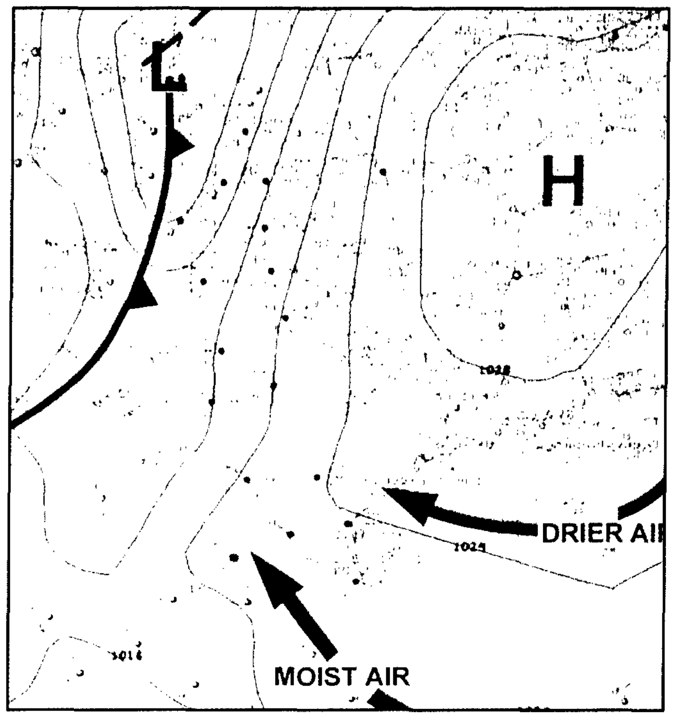

Figure 4-37. Surface, 2100Z/25 January 2001

Figure 4-38 illustrates the afternoon weather depiction chart (nephanalysis). Stratus advection is evident—the solid line represents ceilings >3,000 feet. The dashed line represents ceilings >5,000 feet.

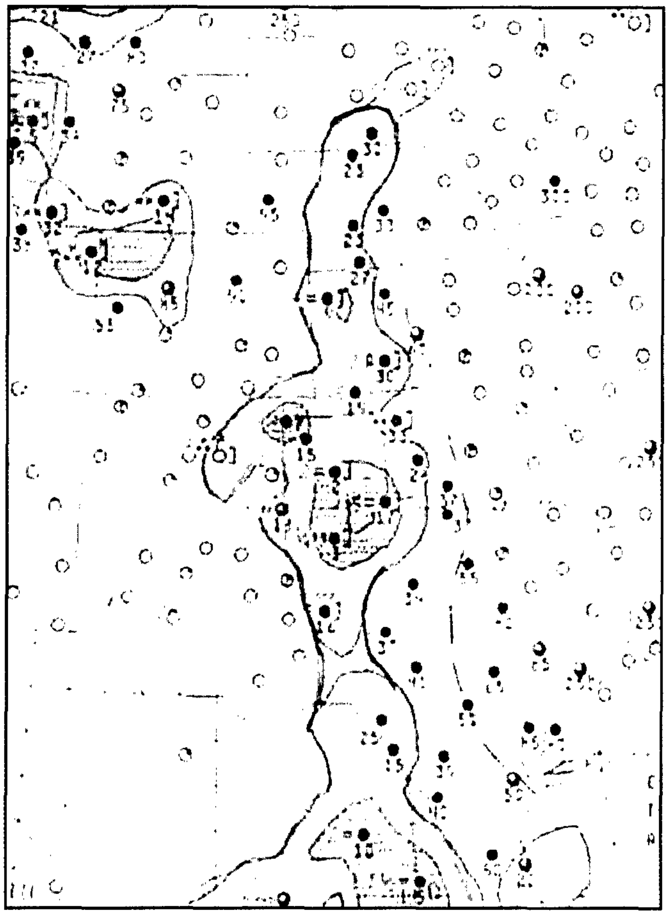

Figure 4-38. Weather Depiction (Nephanalysis), 2200Z/25 January 2001

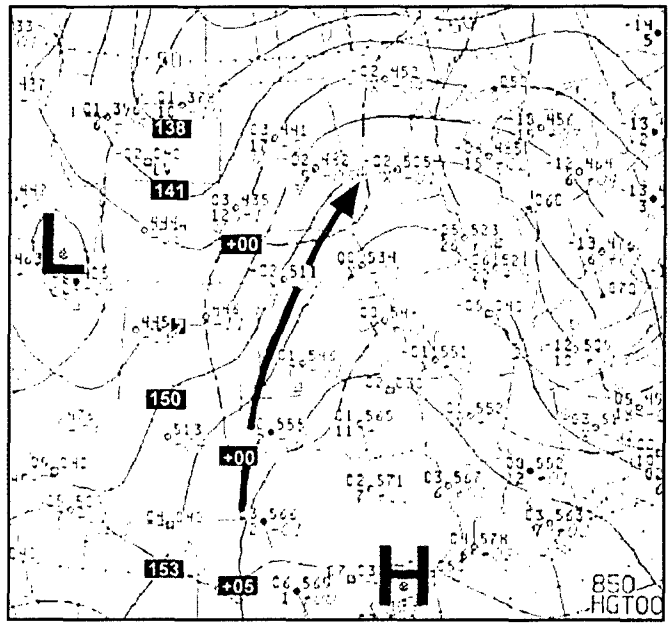

Figure 4-39. 850 mb, 1200Z/25 January 2001
Low-level jet has formed. The jet pattern follows the model shown in Figure 4-31.

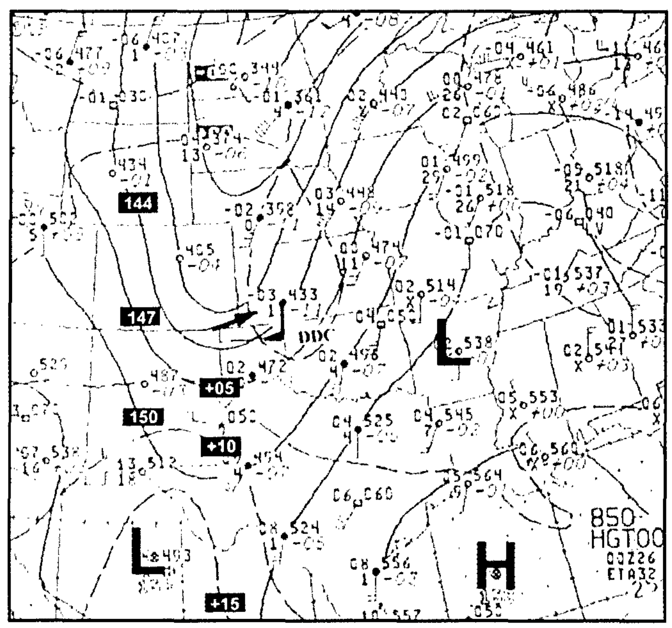

Figure 4-40. 850 mb, 0000Z/26 January 2001
Low-level jet continues over the Western Plains (50-knot max). Note: Boundary winds would be more helpful to determine stratus advection tracks since winds would be more southerly.

Figures 4-39 and 4-40 depict the 850 mb data during Type 1 Gulf stratus advection. At 1200Z (Figure 4-39), the low-level jet appears over the western High Plains with a max speed of 40 knots. Twelve hours later (Figure 4-40), the jet is still shown in the same area with a max speed of 50 knots at DDC (see arrow).

Type 2 Gulf Stratus

When an extensive surface anticyclone circulation moves into the northeastern CONUS, strong southeasterly flow is established within the low levels through the Gulf. The first evidence of this type advection can occur anywhere along the Texas coast, depending on where the low-level moist flow is located. Two main tracks are shown in Figure 4-41 over southern Texas. Initial reports from the coastal stations can begin at any time. Ceilings are generally at 2,500 feet with tops at 5,000 feet during the first few hours. Type 2 Gulf stratus advects reliably into the Central Plains and is always thick enough to preclude dissipation.

Figure 4-41. Type 2 Gulf Stratus Advection Track and LLJ Position

Figures 4-42, 4-43 and 4-44 illustrate three examples of Type 2 Gulf stratus advection. The white arrow shown in Figure 4-44 points to thin cirrus overlying the stratus. Often cirrus forms on the eastern side of the Rocky Mountains and other mountain ranges over the western CONUS (presented earlier in Chapter 2).

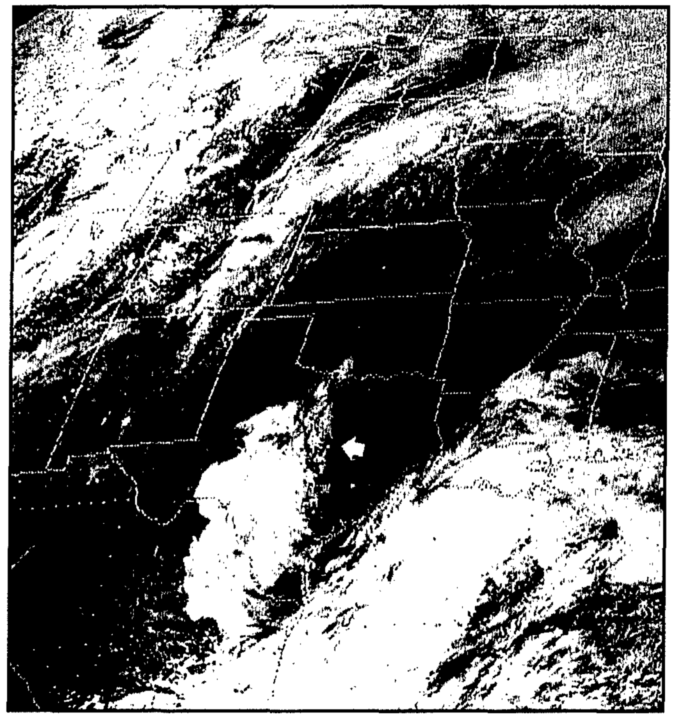

Figure 4-42. GOES-E VIS, 2030Z/ 14 February 1981
Arrow notes Type 2 Gulf stratus advection over Texas.

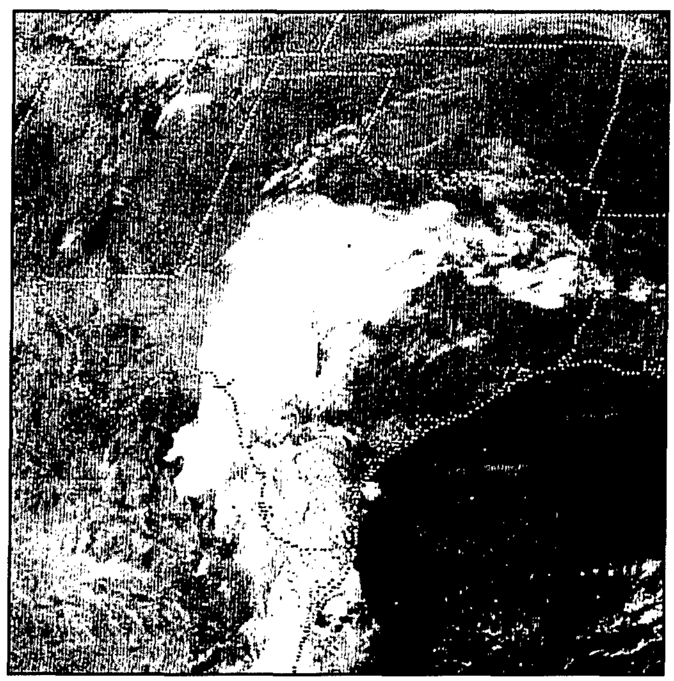

Figure 4-43. GOES-E VIS, 1630Z/ 9 March 1984

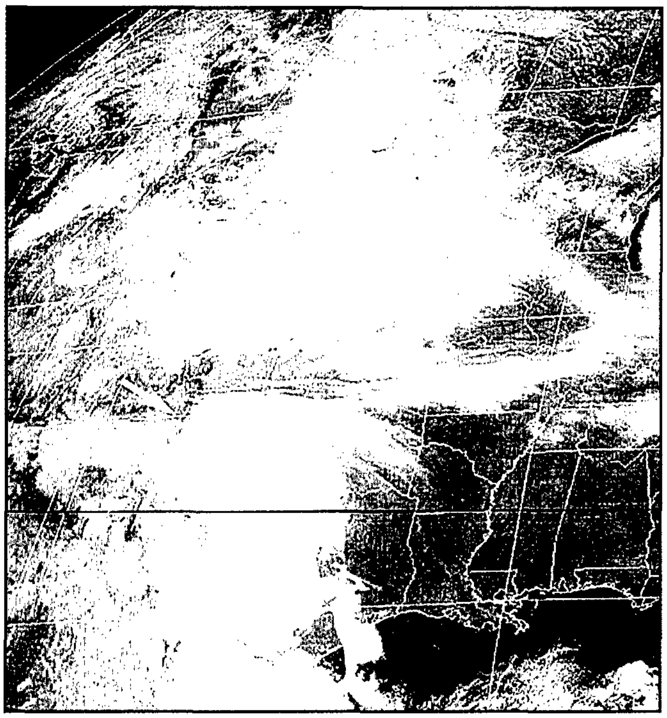

Figure 4-44. GOES-E VIS, 1825Z/ 5 December 2000
A tongue of Gulf moisture is easily seen over the Southern Plains to the Gulf of Mexico.

Type 3 Gulf Stratus

The stratus advection type shown in Figure 4-45 and 4-46 occurs when there is a strong moist flow from the Gulf below 2,000 feet and dry southwesterly flow above. The 850 mb chart will usually reflect dry air throughout most of Texas. Upslope stratus forms over the rising terrain in south-central Texas, usually in the San Antonio, Austin and Junction area, and spreads rapidly northward. Formation always begins at night, usually between 0500Z and 1300Z. Preceding stratus formation, skies are generally clear or partly cloudy. Surface winds are between 5 and 10 knots and the temperature-dew point spread is small. Frequently, the low-level jet is found further south and is near the boundary level. Ceilings form near 1,500 feet, and the stratus is typically about 2,000 feet thick. The stratus usually advects rapidly northward, following the primary track ahead of cold fronts located in central Oklahoma, Kansas and Nebraska. A secondary cyclonic track sets up (dashed track) when strong lows develop along mP frontal systems moving out of the Rockies (i.e., Colorado Low). Low-level jet streams are usually intense resulting in rapid stratus development and advection westward into the developing low.

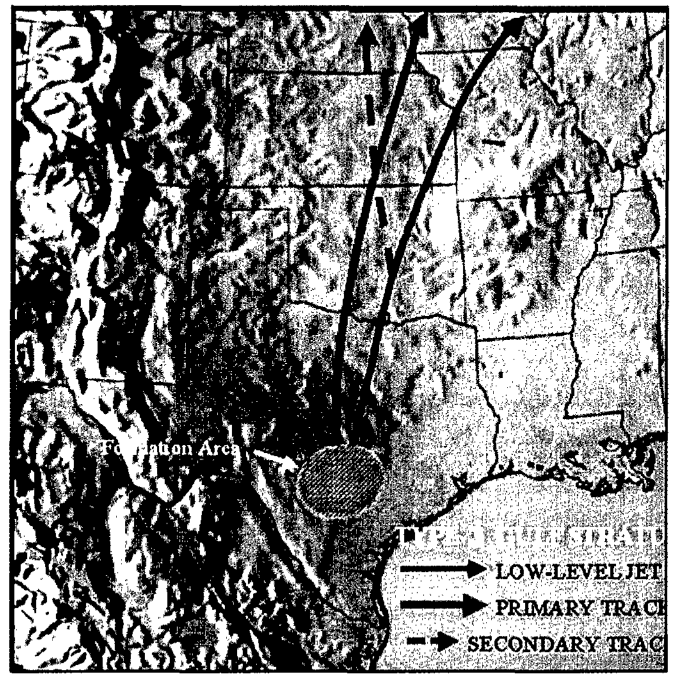

Figure 4-45. Type 3 Gulf Stratus Advection Tracks and LLJ Position

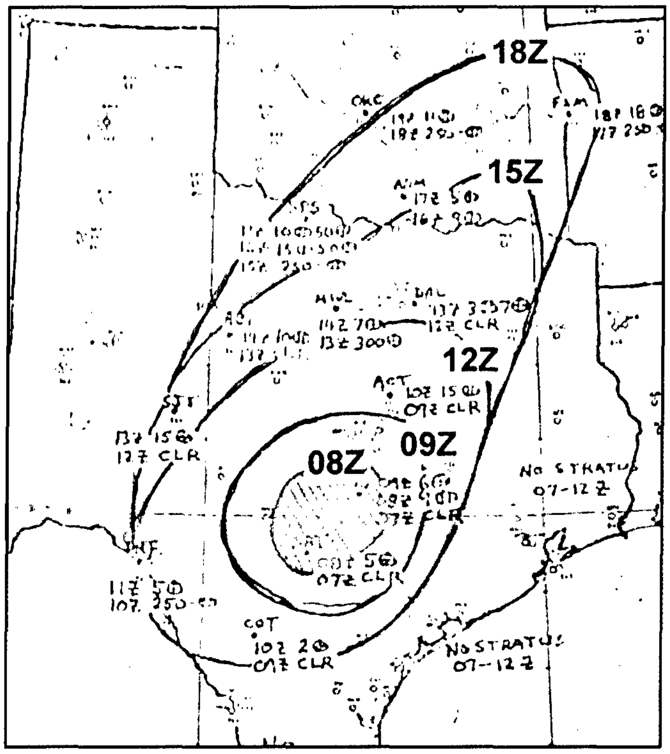

Figure 4-46. Type 3 Gulf Stratus Advection Stratus formed over the San Antonio-Austin area near 0800Z as shown by the hatched area.

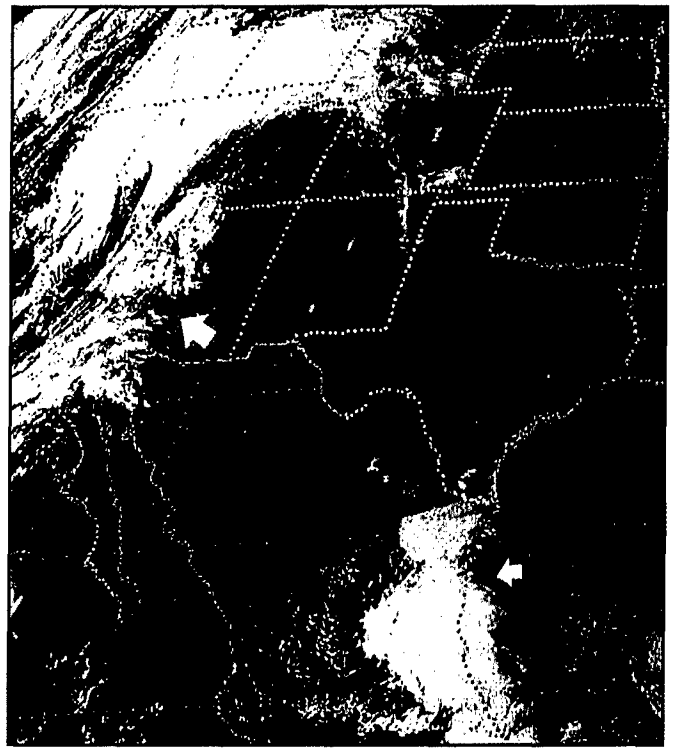

Figure 4-47. GOES-E VIS, 2216Z/ 3 November 1979

The following two examples are presented to enlighten forecasters on how Gulf moisture can travel northward from Texas to the Central Plains ahead of an approaching cold front. In Figure 4-47, stratus in seen over eastern Mexico (arrow); the larger arrow shows a Pacific cold front. In Figure 4-48, 42 hours later, the moisture has spread northward into Missouri as indicated by the arrows. Whiteman AFB, Missouri (KSZL) is affected by nearly all Type 2 and Type 3 Gulf stratus advection events (study was done at KSZL in the early 1960s by the author).

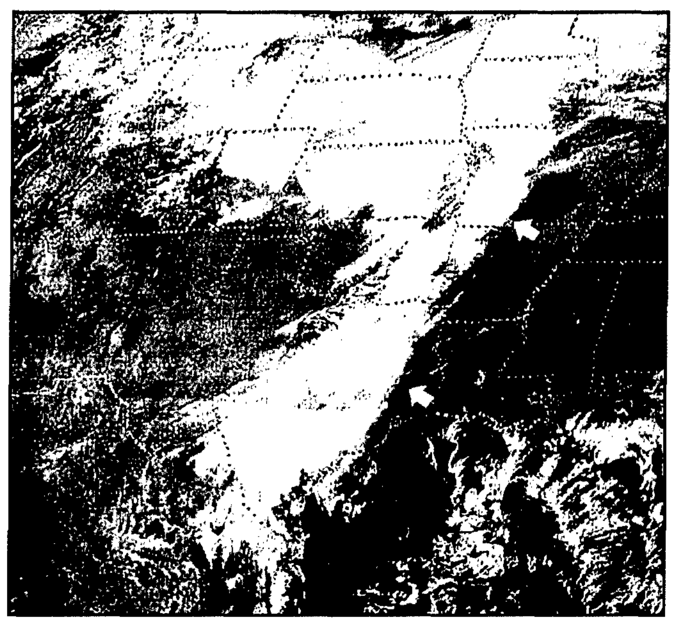

Figure 4-48. GOES-E VIS, 1646Z/ 5 November 1979
42 hours later than Figure 4-47.

A second example is shown in Figure 4-49 and 4-50. In Figure 4-49, Type 2 advection has reached into north central Texas. Within 24 hours, Gulf stratus advected into Missouri and Illinois (Figure 4-50).

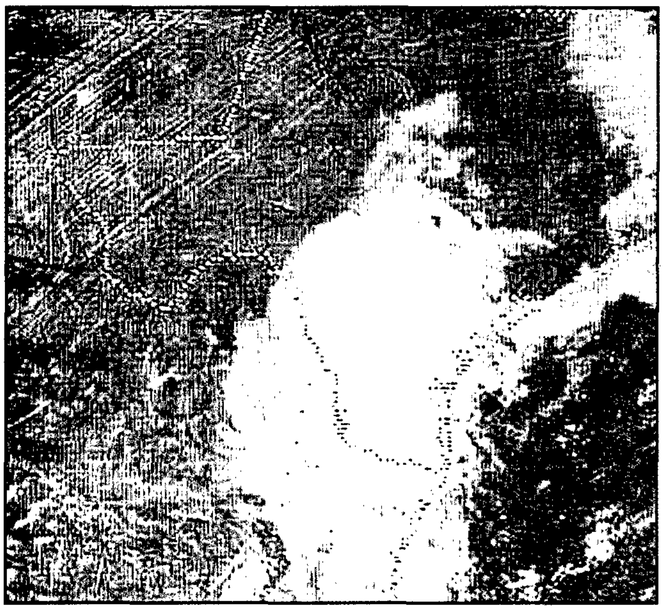

Figure 4-49. GOES-E VIS, 1930Z/ 3 December 1980
The cloud area over eastern Texas is fog.

Finally, two other considerations in tracking stratus advection are shown in Figures 4-51 through 4-54. Enhanced IR satellite pictures can provide forecasters with an additional tool for forecasting the extent of warm air advection stratus and fog at night. Frequently, areas where fog and stratus are more likely to form over or advect into will appear as relatively dark areas on enhanced satellite pictures (called "black stratus"). These dark areas are normally found downwind from a moisture source, such as the Gulf of Mexico and appear to outline the boundary of relatively moist air in the lower levels. In Figure 4-51, a dark area appears over southeast Texas as indicated by the white arrow. During the night, moist air absorbs the earth's radiation, becomes warmer, and reradiates this energy in all directions, part of it back towards the earth. In areas not covered with moist air, the earth's radiation is loss to space. The net effect is a warmer earth in areas covered by air with high moisture content that appears darker on IR photographs.

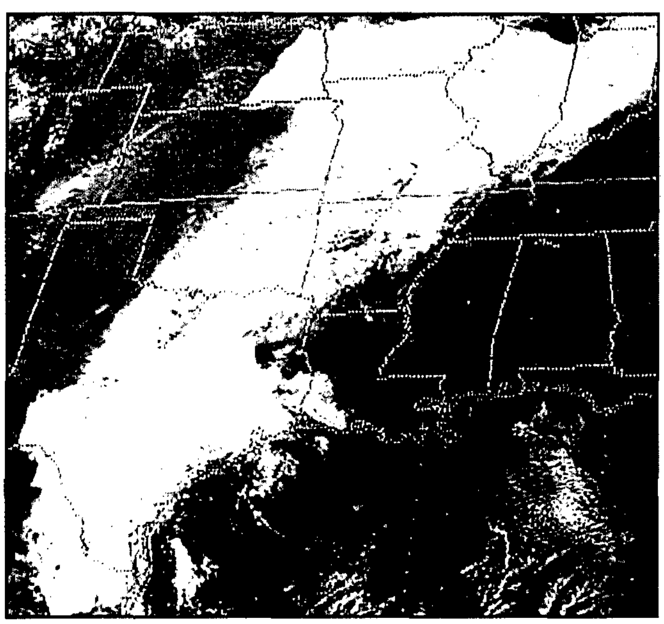

Figure 4-50. GOES-E VIS, 1840Z/ 4 December 1980
24 hours later than Figure 4-49.

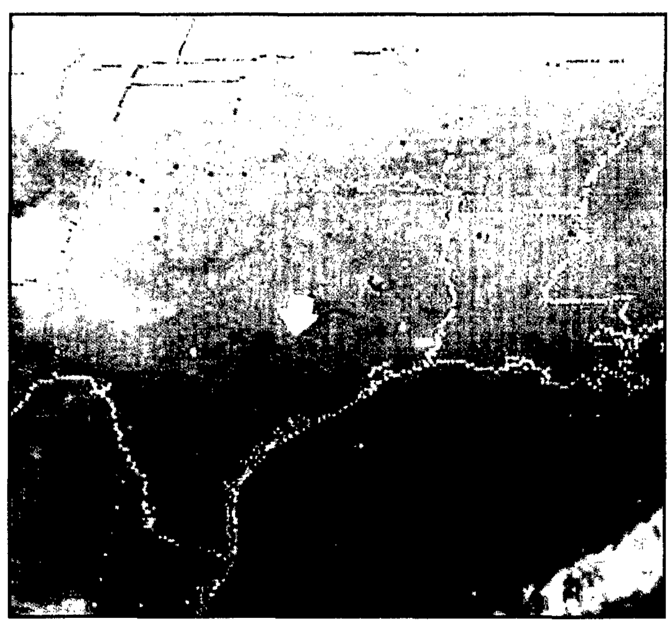

Figure 4-51. GOES-E IR, 1200Z/ 28 January 1981
Arrow points to the "black stratus."

Gulf Stratus Advection Tracks

Gulf stratus advection occurs frequently during the nocturnal period. Visible photos are not available during this period. In the IR, stratus appears as a dull shade of gray if they can be seen at all (Figure 4-52). Often, due to a temperature inversion during the cold season, the temperature of the land surface is colder than the temperature at the top of the cloud. If this occurs, it is nearly impossible to see stratus on an IR photo. Figures 4-53 and 4-54 illustrate this stratus identification problem. A cP air mass prevails over the Midwest. A stratus layer exists from Texas northward into Kansas, but it is difficult to see because of the cold terrain as shown in Figure 4-53. Five hours later, Figure 4-54, the stratus tongue is more discernible across the Great Plains. A greater contrast between the cloud layer and terrain evolved due to increased surface heating.

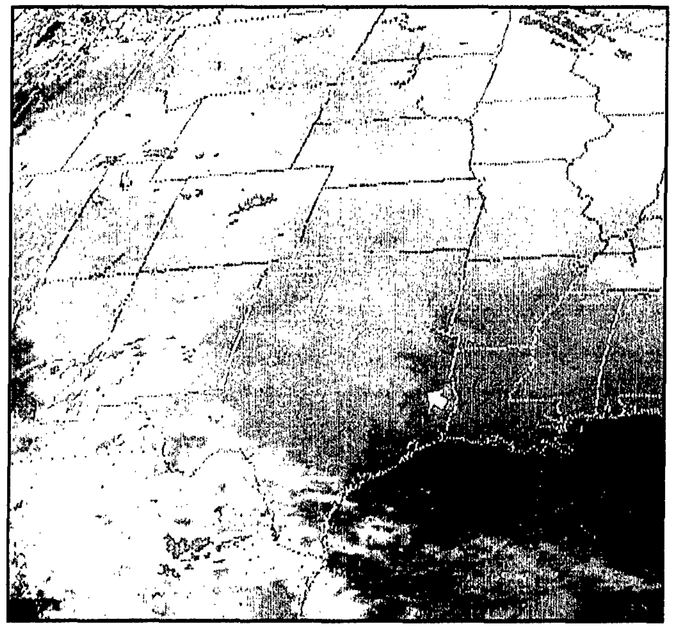

Figure 4-53. GOES-E Enhanced IR, 1400Z/ 10 January 1981

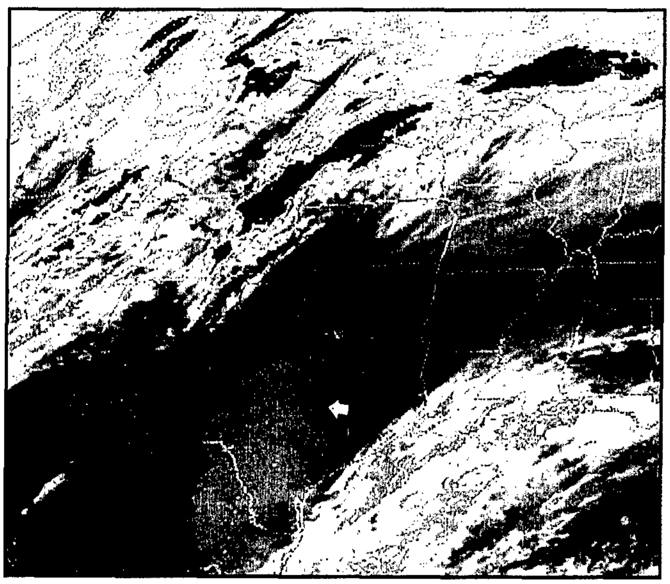

Figure 4-52. GOES-E Enhanced IR, 2001Z/ 14 February 1981

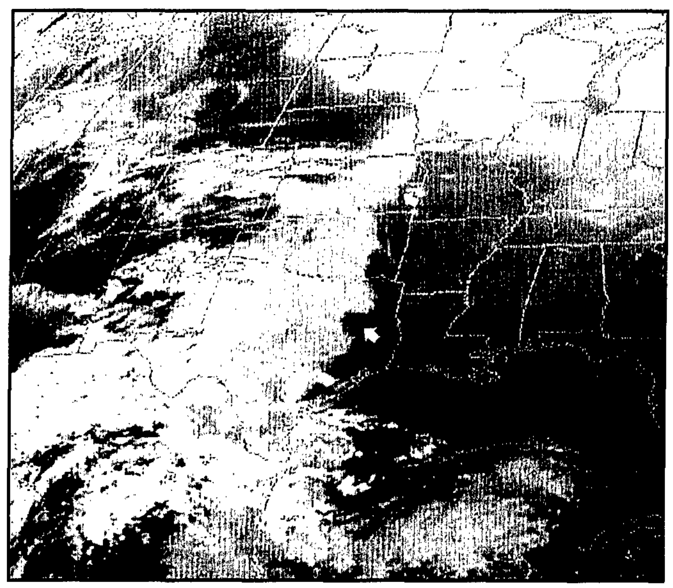

Figure 4-54. GOES-E Enhanced IR, 1900Z/ 10 January 1981

Post-frontal stratus systems (residual) sometimes "hang up" over the Gulf of Mexico as depicted in the following visible and IR photos, Figures 4-55 through 4-57. Forecasters should pay attention to these systems when low-level winds return to a southerly component and the possibility exists for northward stratus advection. In Figure 4-55, warm air stratus is shown over eastern Mexico while cold air stratocumulus prevails over most of the Gulf. Figure 4-56 depicts an infrared morning image of stratus advection. Small narrow streaks shown in Figure 4-56 over southern Texas are cirrus streaks. In Figure 4-57, stratus advection from the Gulf covers a large area of eastern Mexico and has spread into southern Texas.

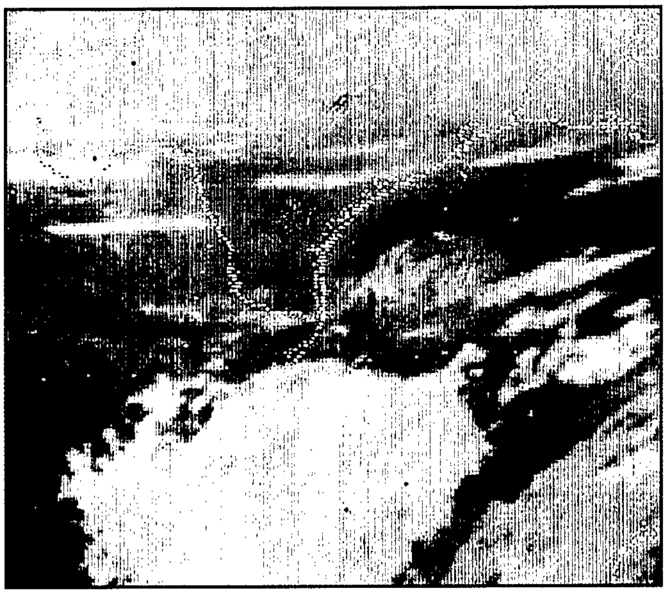

Figure 4-56. GOES-E IR, 1600Z/ 2 February 1981

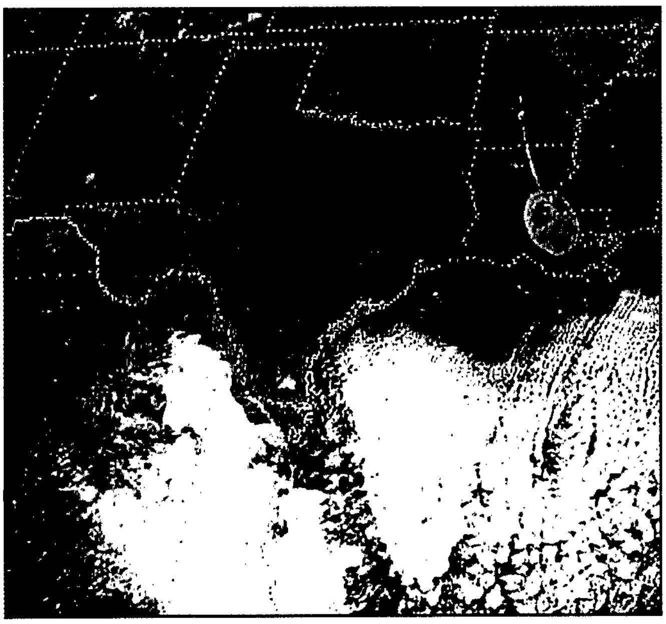

Figure 4-55. GOES-E VIS, 1616Z/ 14 November 1979
Extensive stratus/stratocumulus across the Gulf of Mexico.

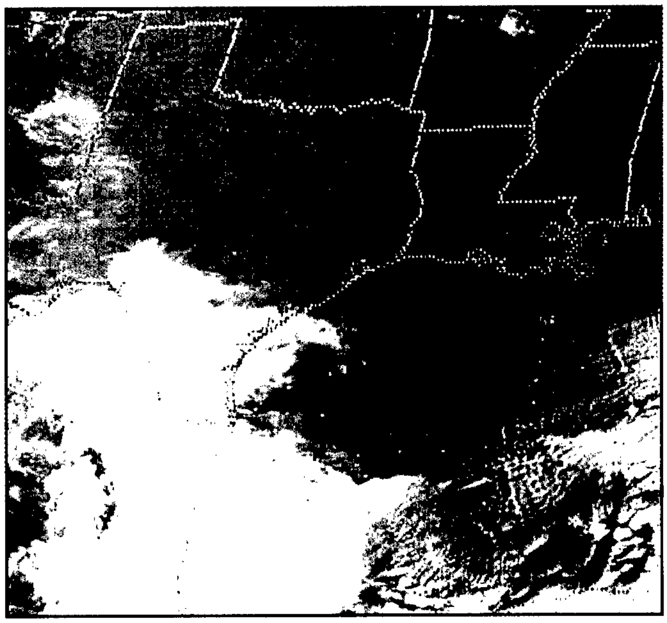

Figure 4-57. GOES-E VIS, 1740Z/ 3 February 1981

Canadian and Northern Rocky Mountain Cyclogenesis

Cyclogenesis along the polar frontal boundary in the vicinity of the Canadian Rockies in southern Alberta (Figure 4-58) and the northern Rockies in Montana (Figure 4- 60) may occur throughout the period. System development can be followed in Figures 4-59 through 4-62. These systems usually develop when the upper flow is aligned northwest to southeast across the CONUS. A strong short wave (Figures 4-59 and 4-61) approaches the polar front and triggers cyclogenesis. Strong gusty surface winds associated with the developing storm cover a large area of the northern Rockies, central and northern Midwest and eastward. Significant snowfall may occur across the Dakotas eastward to the Great Lakes (see Figure 4-62).

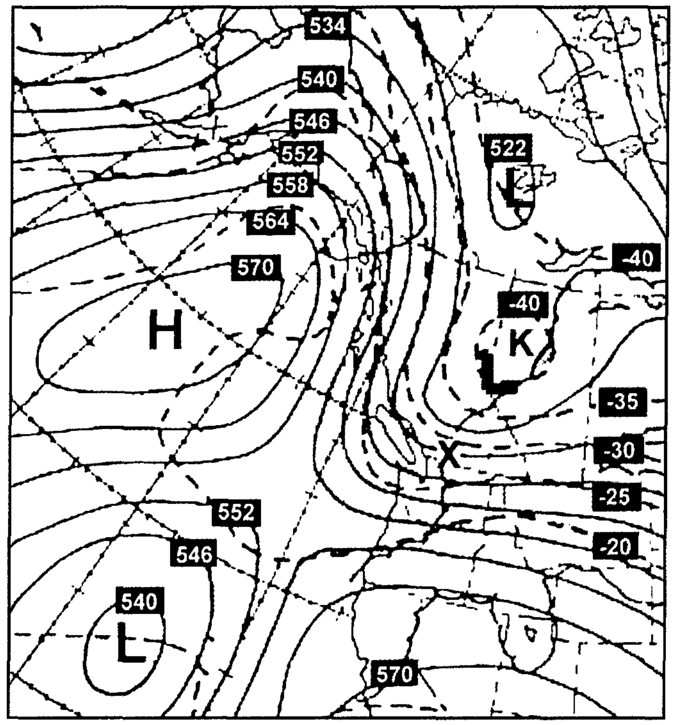

Figure 4-59. 500 mb, 1200Z/5 January 1980

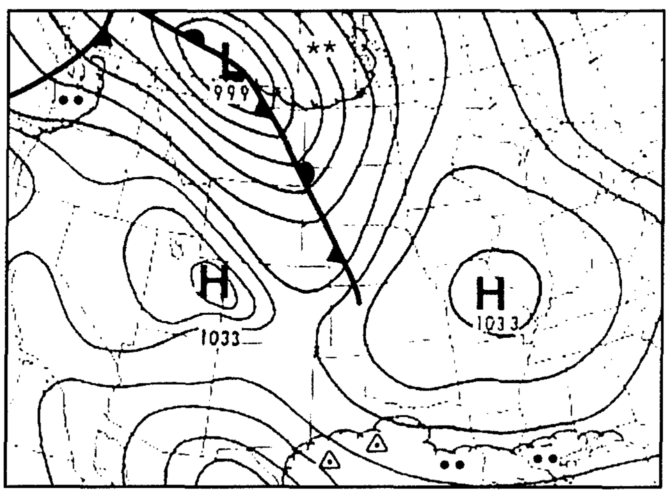

Figure 4-58. Surface, 1200Z/5 February 1979
Strong Alberta Low development.

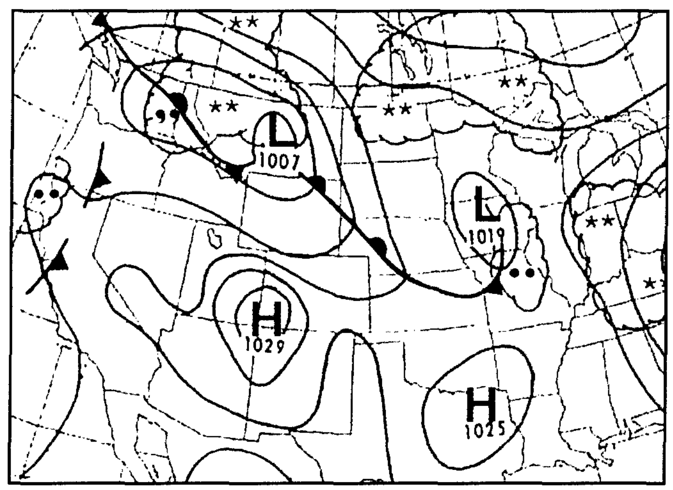

Figure 4-60. Surface 1200Z/5 January 1980
Frontal wave has developed over Montana as Canadian short wave approaches.

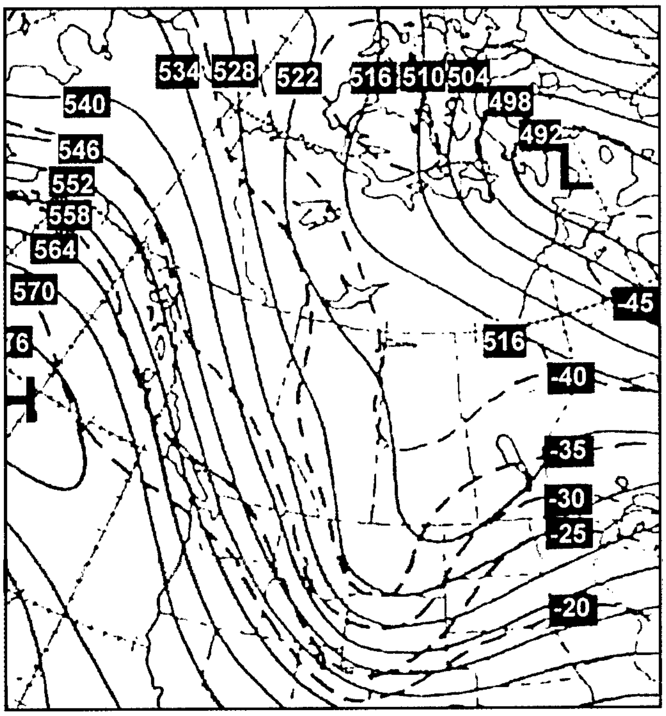

Figure 4-61. 500 mb, 1200Z/6 January 1980
Short wave has moved into the northern Rockies.

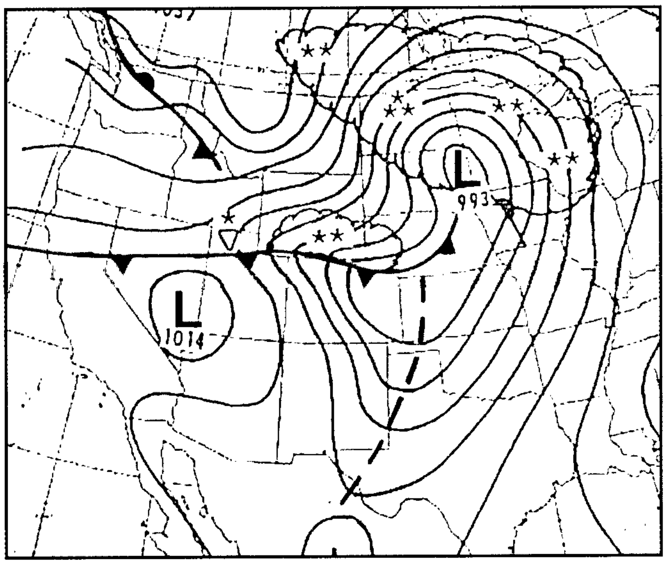

Figure 4-62. Surface, 1200Z/6 January 1980
Surface low has moved southeastward and deepened 14 millibars. Strong winds and accumulating snowfall over the northern Great Plains.

A second example is shown how the NGM forecast an Alberta system during a 24-hour period (24 and 36 hour forecasts). Verification showed the NGM forecasts were right on track (not shown). A short wave is forecast within a strong northwest-southeast mid-level flow (Figure 4-63). A developing frontal low is forecast over southern Alberta (Figure 4-64). A strong pressure gradient should produce strong surface winds over Montana and Wyoming.

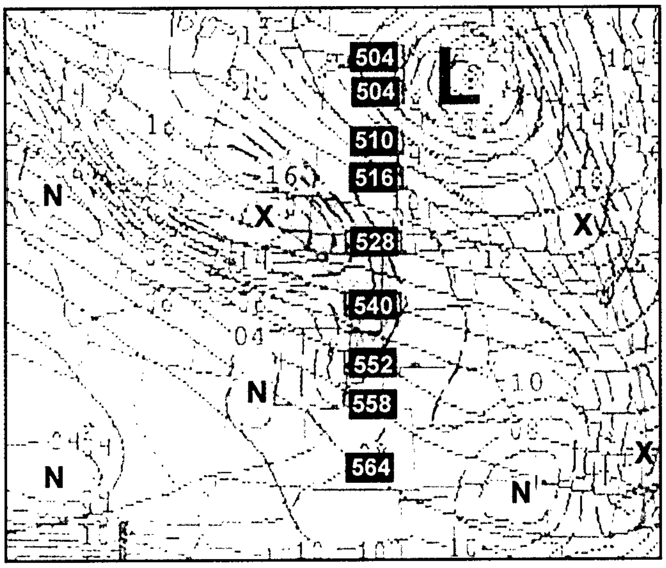

Figure 4-63. 24HR 500 mb HEIGHTS/VORTICITY, 0000Z/3 February 1999

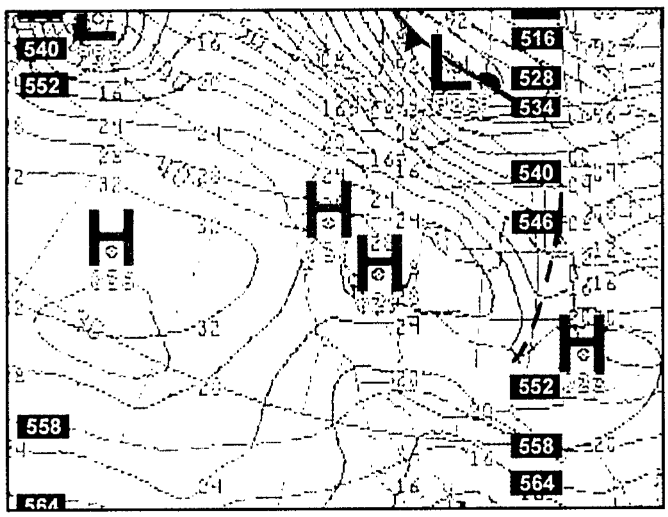

Figure 4-64. 24HR MSL PRES/1000-500 mb THKNS, 0000Z/3 February 1999

Twelve hours later, Figures 4-65 and 4-66, the developing short wave is expected over the Northern Plains, and the surface low is forecast over eastern North Dakota. The short wave is expected to continue to deepen over the Northern Plains. Strong surface winds are likely to occur across the northern and central Great Plains during the next 24-36 hours.

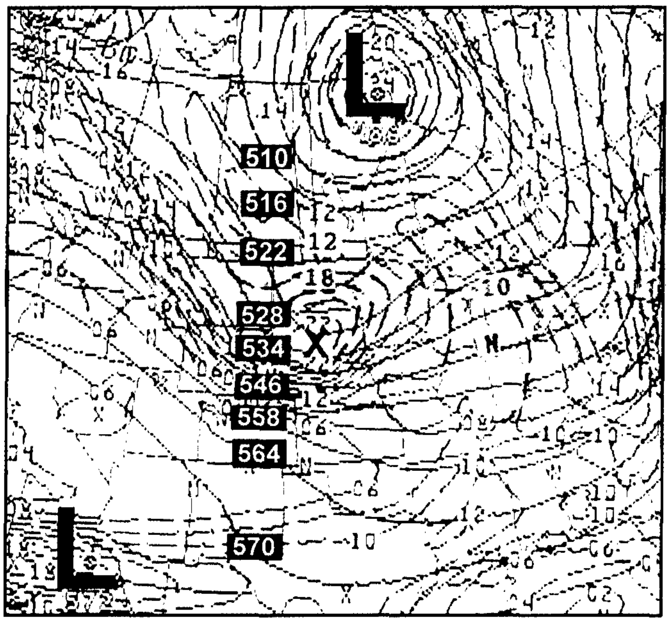

Figure 4-65. 36HR 500 mb HEIGHTS/VORTICITY, 1200Z/3 February 1999

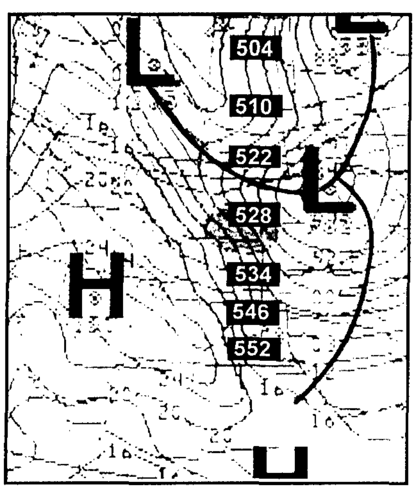

Figure 4-66. 36HR MSL PRES/1000-500 mb THKNS, 1200Z/3 February 1999

Cyclogenesis over the Northern Great Plains

Polar and arctic air masses, building over the snowfields of western Canada, are poised to drop into the CONUS and spread their winter weather over the eastern two-thirds of the CONUS. Often, it only takes a developing frontal wave on the polar front over the Northern Plains/southern Canada that sets the Canadian air mass in motion. In Figure 4-67, a stationary polar front lies across the Northern Plains. A large cP air mass is shown over western Canada.

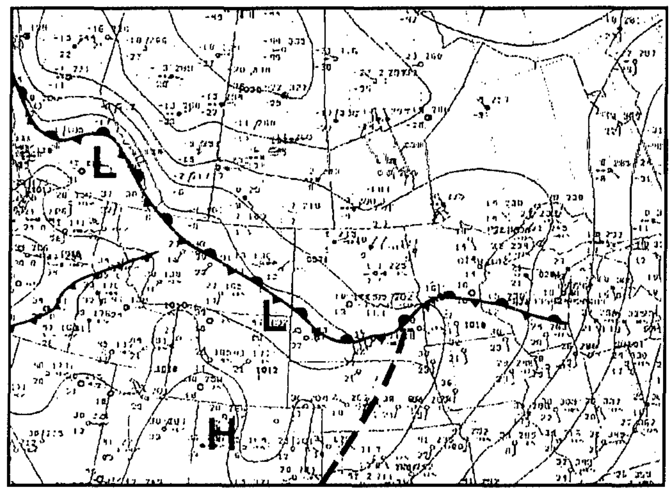

Figure 4-67. Surface, 1500Z/15 January 2000

The following example, presented in Figures 4-68 and 4-69, shows a polar frontal wave moving across the Dakotas. In Figure 4-69, cold frontogenesis is shown over Minnesota and Wisconsin that indicates the Canadian air mass is on the move.

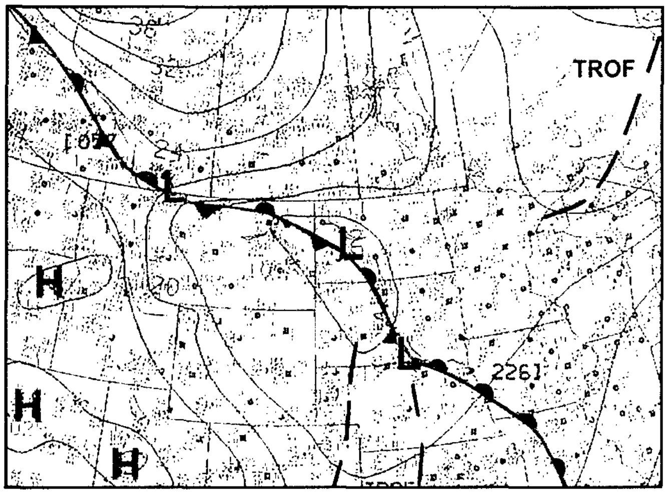

Figure 4-68. Surface, 0000Z, 6 January 1999
Frontal wave has developed over western South Dakota. Ridging (cP) stationary over southern Canada ready to move south.

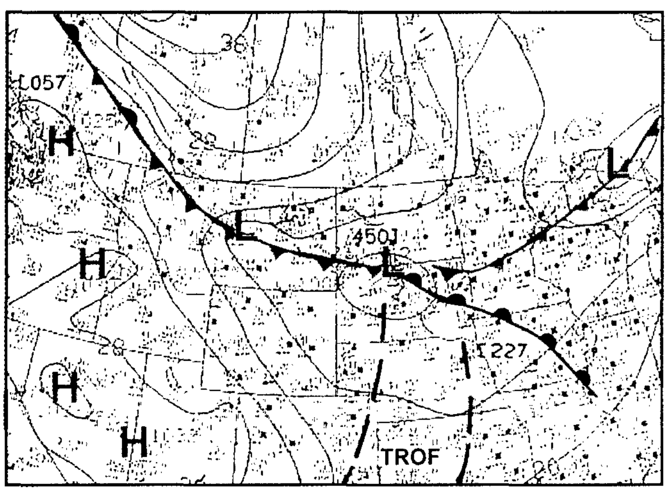

Figure 4-69. Surface, 0300Z, 6 January 1999
Cold frontogenesis is shown over Minnesota and Wisconsin as Canadian air begins to move southward.

The following illustrations (Figures 4-70 through 4-73) are the NGM 24 hour and 36 hour forecasts based on the initial hour of 0000Z 05 January (12 hours before cP air mass movement southward).

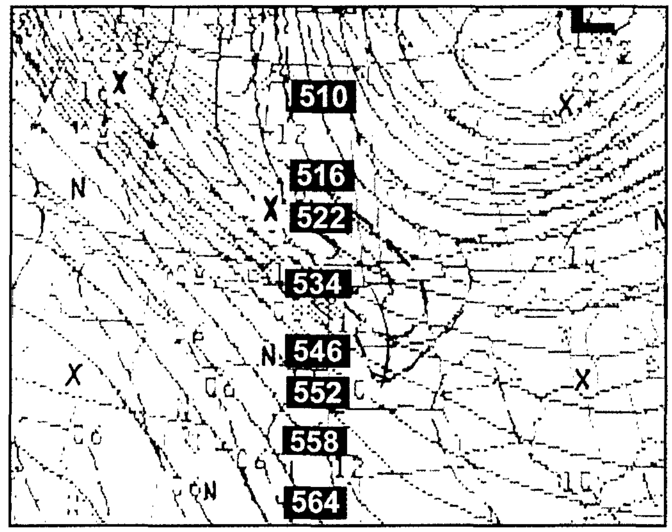

Figure 4-70. 24HR 500 mb HEIGHTS/VORTICITY, 0000Z/6 January 1999
Short wave/PVA forecast to move into the Dakotas.

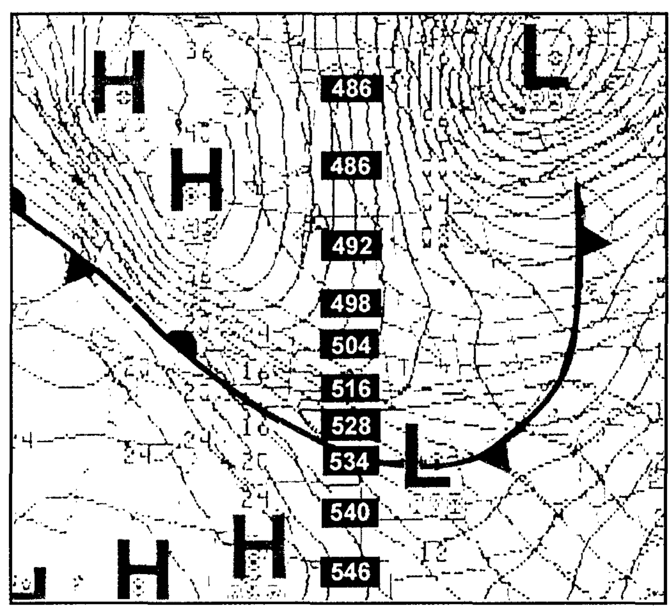

Figure 4-71. 24HR MSL PRES/1000-500 mb THKNS, 0000Z/6 January 1999
Polar air forecast to push southeastward.

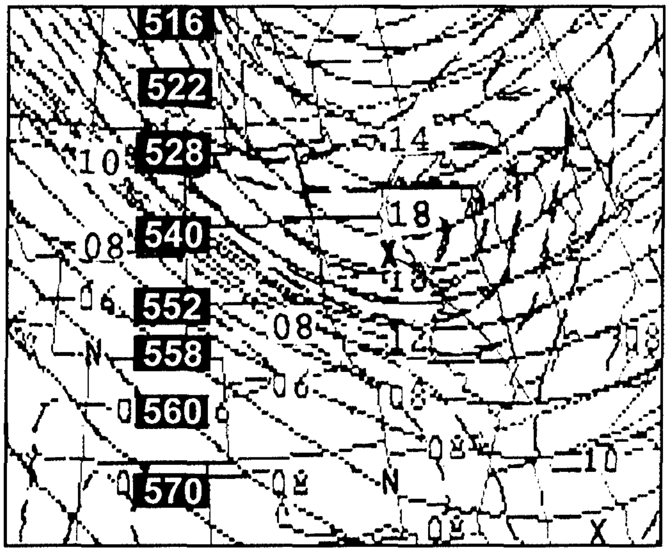

Figure 4-72. 36HR 500 mb HEIGHTS/VORTICITY, 1200Z/6 January 1999
PVA forecast to move into the Great Lakes.

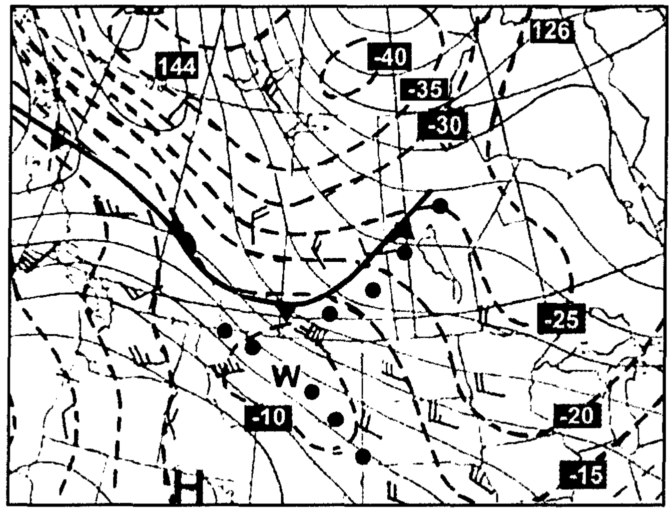

Figure 4-74. 850 mb, 1200Z/7 January 1982
Canadian air masses that are on the move southward may be detected at the 850 mb level. Note that a cold front can be placed in the thermal ridge.

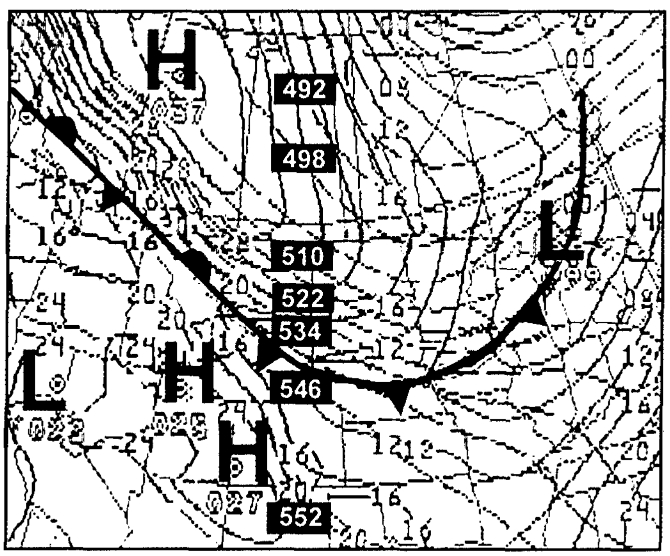

Figure 4-73. 36HR MSL PRES/1000-500 mb THKNS, 1200Z/6 January 1999
Canadian air forecast into the Central Plains.

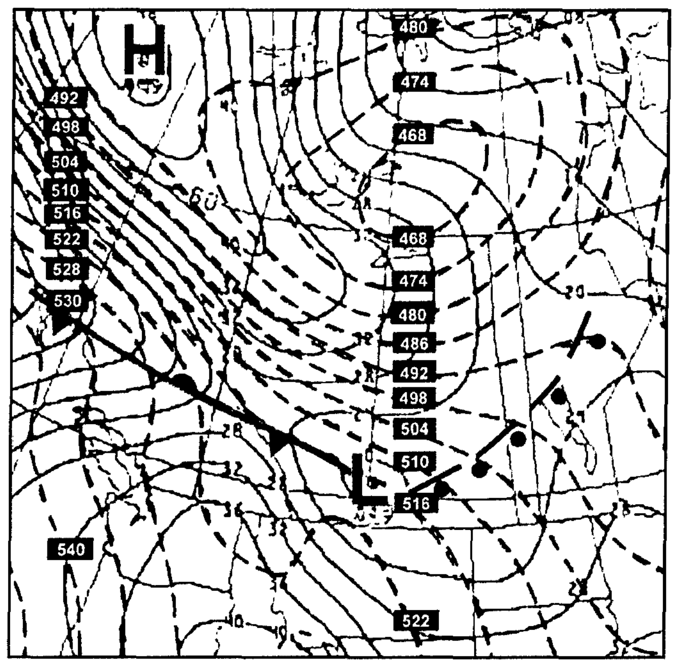

Figure 4-75. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/7 January 1982
Thickness ridge shown in same area as the 850 mb thermal ridge and supports cold frontogenesis (noted by the trough).

Developing low-level thermal ridges at the boundary and 850 mb levels (Figure 4-74) and thickness ridges on model data (Figure 4-75) should alert forecasters that air mass changes are likely to begin.

Cyclogenesis over the Central and Southern Great Plains - Receding High

Forecasters located across the eastern Rockies and the Great Plains should always be on the alert for rapid intensification of surface lows moving out of the Rocky Mountains. The model shown in Figure 4-76 depicts a typical surface regime when high-pressure systems move to the eastern CONUS. Occasionally, a significant Rocky Mountain storm develops (Colorado Low) on the approaching mP cold front as upper-level cyclogenesis occurs. Figure 4-76 shows typical surface conditions 12 to 24 hours prior to a major storm over the Midwest. Of course, there will be many variations to this model. It is important for the forecasters to identify the more important features for potential storm development. Each feature noted in Figure 4-76 is identified by a letter.

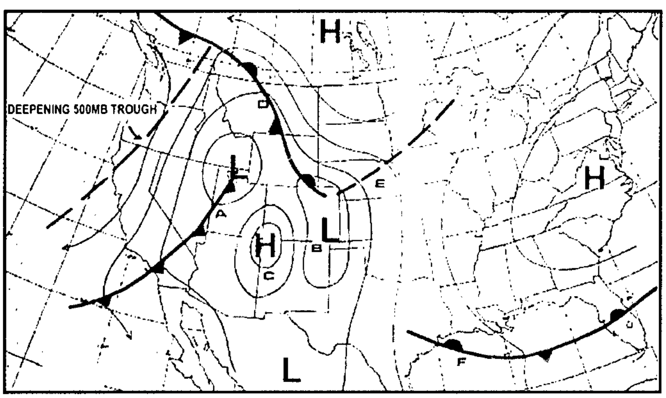

Figure 4-76. Typical Surface Pattern – Receding High

The mP cold front with an associated low (A) is moving easterly towards the Rocky Mountains and is approaching the lee-side low/trough (B). Often, two or more surface lows, along with the lee-side low, will appear over areas west of the Rocky Mountains during upper-level intensification and/or cyclogenesis. Identifying the main surface low and where it will eventually organize can be a problem. The models generally forecast cyclogenesis with these developing systems west of the Rockies; however, identification and steering of the main surface low and where the significant snow will fall can still be a forecast problem. The Great Basin High (C), located over the Colorado Plateau area, appears routinely on the surface chart. The high does not move out ahead of an approaching mP frontal system. Instead, the high will dissipate as warmer southerly low-level flow advects into the region.

There is usually a semi-permanent polar stationary front which extends southeastward from western Canada to eastern Colorado along and east of the Rocky Mountains (D; this feature was presented earlier in Chapter 3). Often, a stationary polar front or trough (leading edge of a stationary Canadian polar air mass) will appear or develop eastward (E) either as front or trough over the central or upper Midwest. The persistence of this feature depends upon the strength of the cP ridge and the northward advection of warmer air. This front or trough can become a significant feature in that it frequently develops the characteristics of a warm front, even though it is often depicted as a stationary front or as a surface trough.

At other times, this east-west surface troughing can be an indicator that colder air is beginning to push southward and that the trough development is the leading edge of cold air. Often, the first appearance of snow will develop along and north of this boundary within the colder air mass many hours prior to main storm development over the central and/or southern Rocky Mountains. The stationary front (F) in the western Gulf of Mexico, under return flow on the backside of the receding high, can also begin moving northward and be accompanied by moist, warm Gulf air. Pacific mP fronts may undergo cyclogenesis within the lee-side trough with the approach of a deepening upper trough. Gulf moisture generally advects northward into these developing storms and adds significantly to system development. Heavy snowfall and strong northerly winds increase across the Western Plains within a few hours as these systems move eastward.

How does one determine that a Rocky Mountain storm may move northward rather than eastward? Several upper-level features should be monitored: the changing configuration of the polar jet located across the central and southern Great Plains and the movements of positive vorticity and height fall centers.

Figures 4-77 and 4-78 depict a model event of a storm system that will produce hazardous winter weather over the Midwest. Figure 4-77 typifies the polar jet orientation during the formative period (Day 1) of short wave cyclogenesis within a zonal flow pattern. In Figure 4-77, **X** indicates the 500 mb positive vorticity center (and most likely the height fall center). Figure 4-78 shows the related surface features.

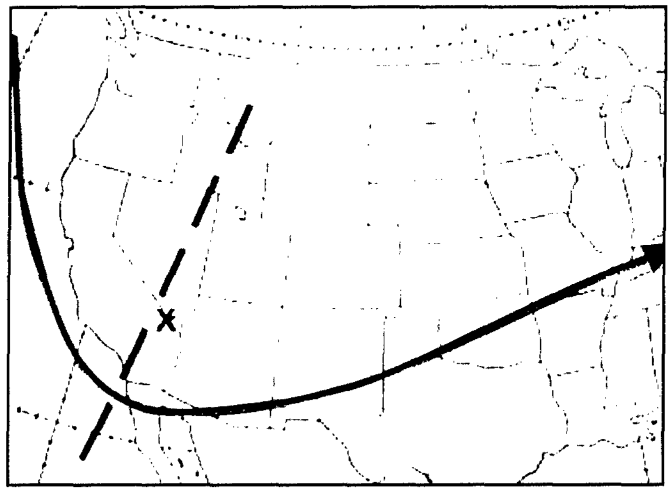

Figure 4-77. Day 1 Model Jet Stream Alignment

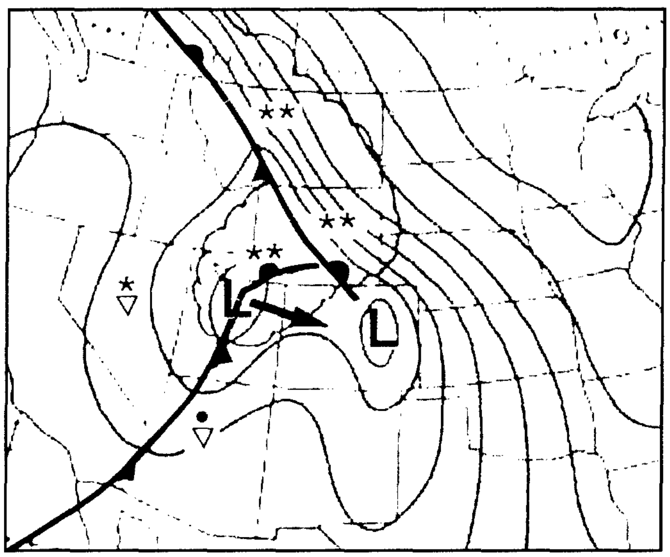

Figure 4-78. Day 1 Model Surface Pattern

If the polar jet eventually becomes aligned southwest to northeast across the central CONUS as shown in Figure 4-79 (Day 2 or 3) then the likelihood of storm movement towards the upper Great Plains should be considered. The positive vorticity and height fall centers never cross the jet stream; they respond to the jet stream's increasingly south to north axis (Figure 4-79) and should turn north as shown by the track (**X**) in Figure 4-79. The surface analysis (Figure 4-80), depicts an intensifying storm system (Colorado Low) over the Central Plains.

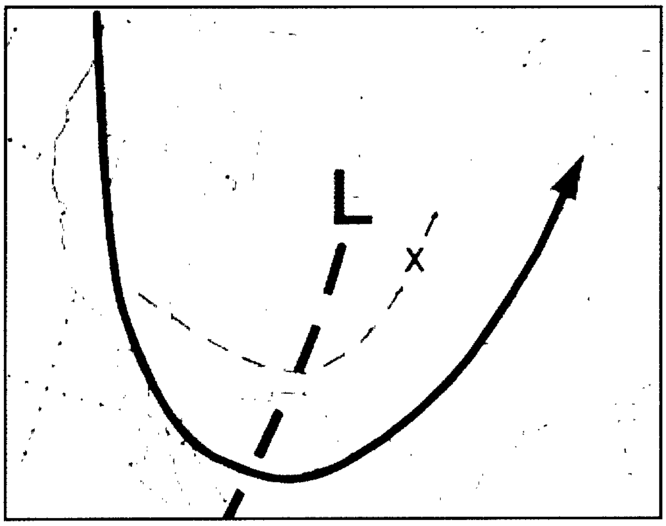

Figure 4-79. Day 2 or 3 Model Jet Stream Alignment
Jet stream amplified. Vorticity/height fall centers lift northeastward to the left of the jet.

Forecasters should always suspect the possibility of upper-level cyclogenesis when mP fronts slow down and begin to wave over the Great Basin as shown in Figure 4-81. Great Basin frontal lows may be a surface reflection of a developing mid-level low (useful information between scheduled upper-air analyses). These systems may eventually become strong storms over the Great Plains. The following day, Figure 4-82, the Great Basin low moved eastward to the southern Rocky Mountains and deepened. The polar front, stationary over the northern Rocky Mountains in Figure 4-81, pushed southward behind the disturbance (Figure 4-82). Increased PVA, overrunning and low-level upslope flow contributed to a large area of snow across the central Rockies and Great Plains.

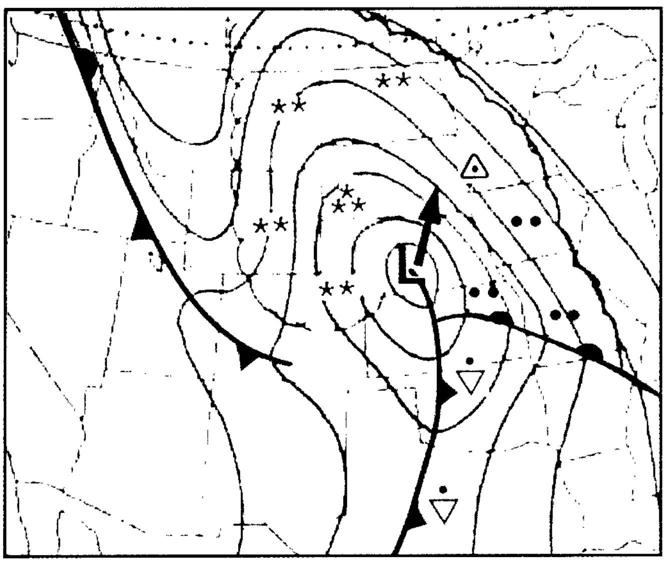

Figure 4-80. Day 2 or 3 Model Surface Pattern
Lee-side low became the main low (Colorado Low). The low intensified and recurved.

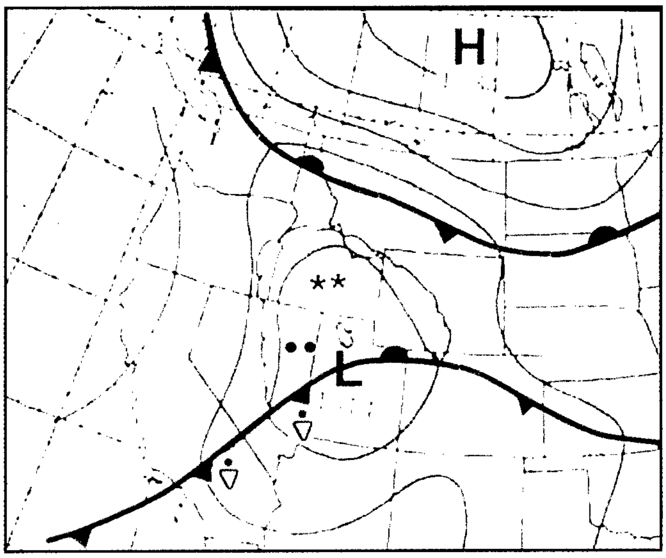

Figure 4-81. Day 1 Surface, 1200Z/ 9 December 1979
Frontal wave over Utah. Polar air mass stationary over the northern CONUS.

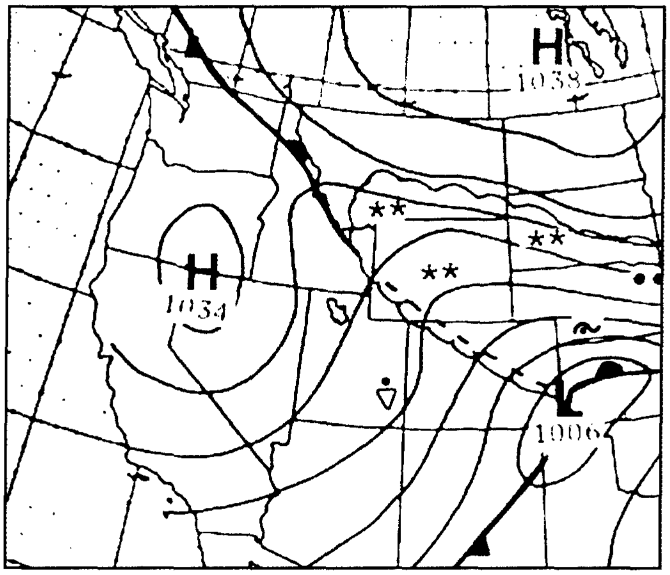

Figure 4-82. Day 2 Surface, 1200Z/ 10 December 1979

The low that formed in Utah has moved into the southern Rockies. Polar air has dropped southward.

Comma Cloud Systems over the Central CONUS - Satellite Interpretation

The satellite information that will be presented in the following pages is to show forecasters how storm systems evolved over the Great Plains with the introduction of warm Gulf moisture and cold Canadian air. Organized comma systems moving over the western CONUS from the Pacific Ocean may become poorly defined in satellite pictures in just a few hours because moisture is depleted while moving across the mountains. A comma cloud system's overall pattern may change significantly within a short period of time, especially with rapid-moving short wave systems. Infrared photos should be used to identify comma cloud patterns. The temperature at cloud top level should enable forecasters to determine how deep the system is and how high the tops are.

The satellite photo shown in Figure 4-83 is approximately 24 hours before a strong storm organize over the Great Plains. Heavy snowfall over the Northern Plains, an ice storm over the Central Plains and severe frontal thunderstorm line across the Southern Plains occurred with this storm (the satellite photo of the Great Plains storm will be shown later). In Figure 4-83, a pronounced southern branch of the polar jet stretches across the eastern two-thirds of the CONUS. A disorganized comma cloud system is shown over the western CONUS (noted by the arrow); the comma system's true configuration is distorted due to foreshortening.

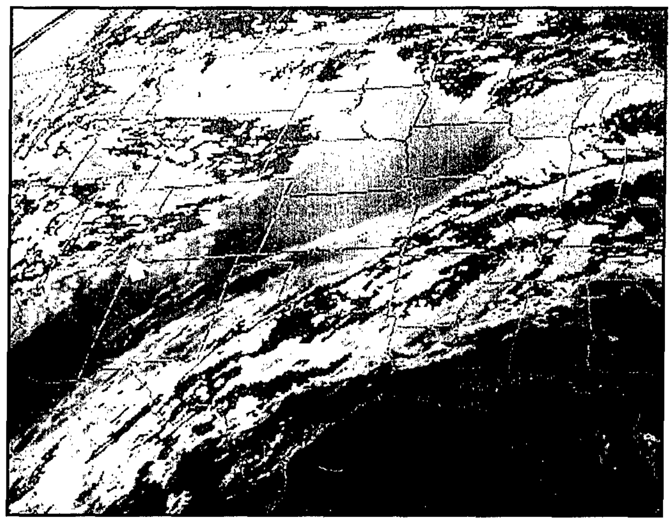

Figure 4-83. GOES-E IR, 0900Z/ 21 January 1982

A brief review of the structure of a comma cloud is introduced at this time. The three primary cloud systems that comprise a comma within the westerlies are shown in Figures 4-84 through 4-86. They are:

- Baroclinic Zone (**A**), Figure 4-84. Highest level cirrus tops. Stratiform clouds. Steady precipitation.
- Vorticity Comma (**B**), Figure 4-85. Mid to low-level clouds. Highly convective. Showery precipitation.
- Deformation Zone (**C**), Figure 4-86. Cirrus level tops. Steady precipitation. Moderate to heavy snowfall in winter.

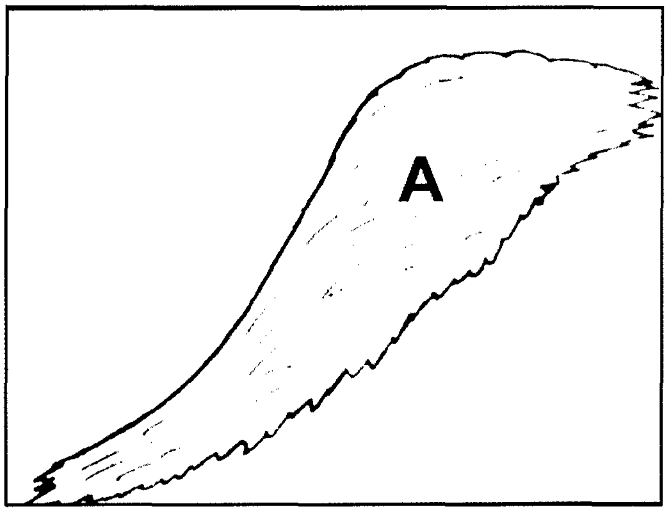

Figure 4-84. Baroclinic Zone Cloud System
Cold/occluded and warm fronts are associated with this cloud pattern.

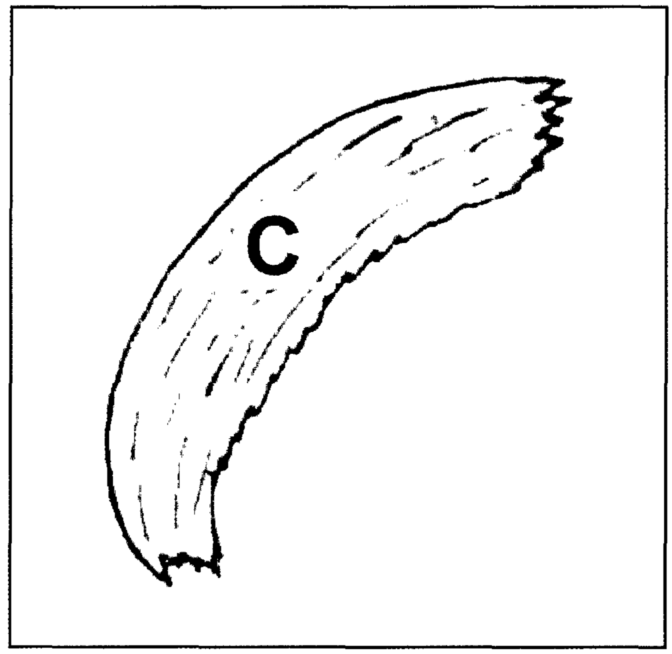

Figure 4-86. Deformation Zone Cloud System
Occluded fronts are associated with this cloud pattern. This cloud system is the heavy snow producer of winter storms.

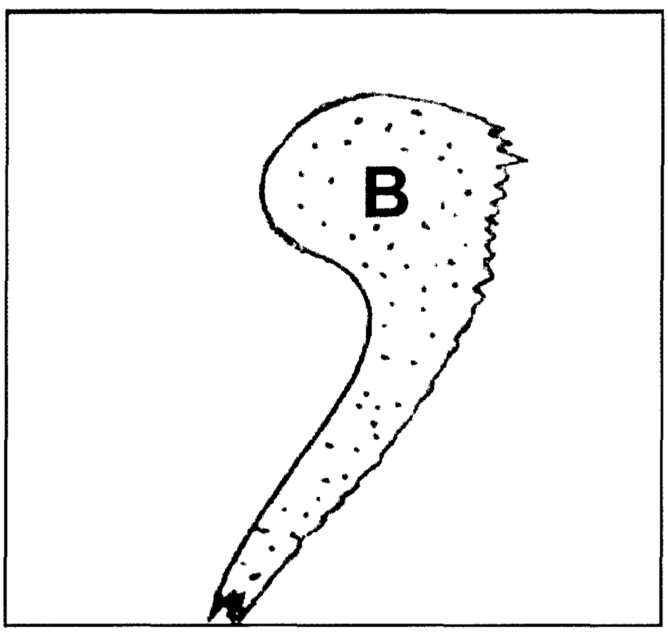

Figure 4-85. Vorticity Comma Cloud System
Cold/occluded fronts are associated with this cloud pattern. Potential for severe thunderstorms.

These three cloud systems have been placed in their respective position in the model of a mature comma cloud system shown in Figure 4-87. Cyclogenesis occurs in different ways, and that the primary consideration for identification of cyclogenesis is the order in which these cloud systems develop. In Figure 4-87, the primary vorticity comma cloud (**B**) is often hidden below the higher-level cirrus layers and cannot be observed on visible satellite photos. The vorticity comma cloud is noticeable in IR photos when thunderstorms tops take on the appearance of a vorticity comma. The upper trough axis can be located where the comma tail becomes fragmented as shown in Figure 4-87.

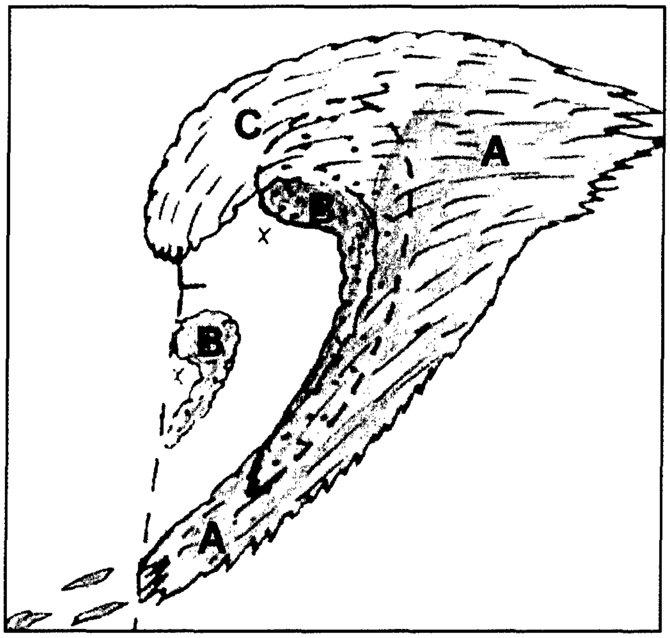

Figure 4-87. Mature Comma Cloud System Composite

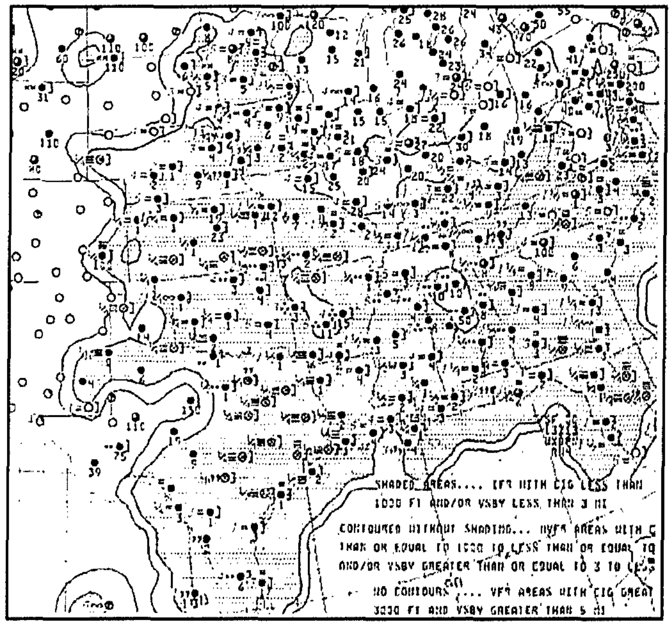

Figure 4-88. Weather Depiction (Nephanalysis), 1300Z/13 February 2001

Cyclogenesis over the Central and Southern Great Plains - Prevailing High

Case studies presented so far were of storm systems that occurred over the Great Plains when transitory surface highs recede to the eastern CONUS. In this section, case studies of storms that occurred within prevailing polar air masses will be shown. In these cases, however, a prevailing high pattern exists over the central and northern Great Plains eastward to the Atlantic Seaboard. Frontal cyclogenesis is shifted southward across New Mexico (i.e., South Pacific or Albuquerque Low) and west Texas, which relates to the polar jet position across southern Texas and the Gulf of Mexico. Overrunning precipitation develops within the cold air many hours before the storm emerges over the central and/or southern Rockies. Movements of height fall centers to determine liquid versus frozen precipitation would not be useful because precipitation is already occurring over the Great Plains long before the upper system arrives. In Figure 4-88, an extensive area of clouds and precipitation covers nearly all of the central and eastern CONUS within a prevailing high-pressure regime.

Extensive clouds and precipitation are shown over a large area of the central and eastern CONUS. Warm air advection over the shallow cold air mass is evident by very low ceilings, fog, drizzle and freezing drizzle over the central and southern Great Plains. Rain is shown over the Mississippi and Tennessee Valley regions and is associated with a short wave.

The example shown in Figures 4-89 through 4-90b reveals how rapid the weather can change within 24 hours (also shown as the Technical Note's cover illustration). This event was dominated by cold polar air over most of the CONUS. Warmer, Gulf air advected northward south of the stationary polar boundary as shown in Figure 4-89. Precipitation intensity and coverage increased when a tongue of warmer Gulf moisture (see arrow in Figure 4-90a) overran the polar stationary or warm front (Figure 4-90b, 15 hours later).

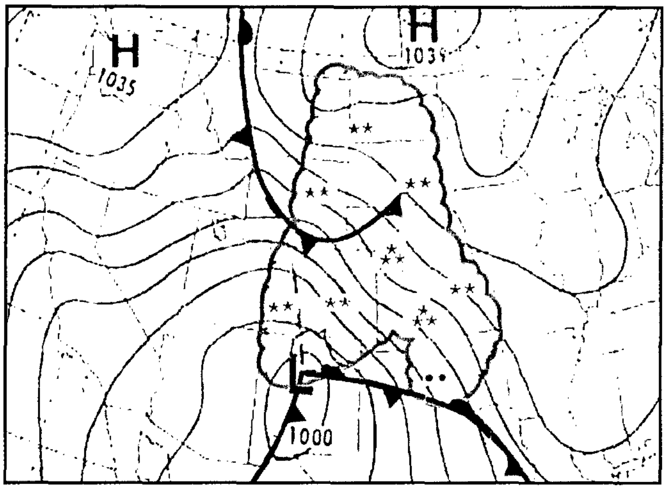

Figure 4-89. Surface, 1800Z/7 February 1980

Generally, this system's movement continued east or southeastward due to the blocking action of the large polar high, and the polar jet stream's position to the south. In Figure 4-90a, the small arrow notes Gulf moisture advection; the larger arrow denotes an approaching short wave. Within 15 hours, Figure 4-90b, the entire Central Plains was covered with clouds. Heavy snowfall blanketed large areas north of the polar front as shown in Figure 4-89.

Figure 4-90b. GOES-E VIS, 1547Z/ 7 February 1980
Extensive cloud cover developed as the storm moved out of the Rockies.

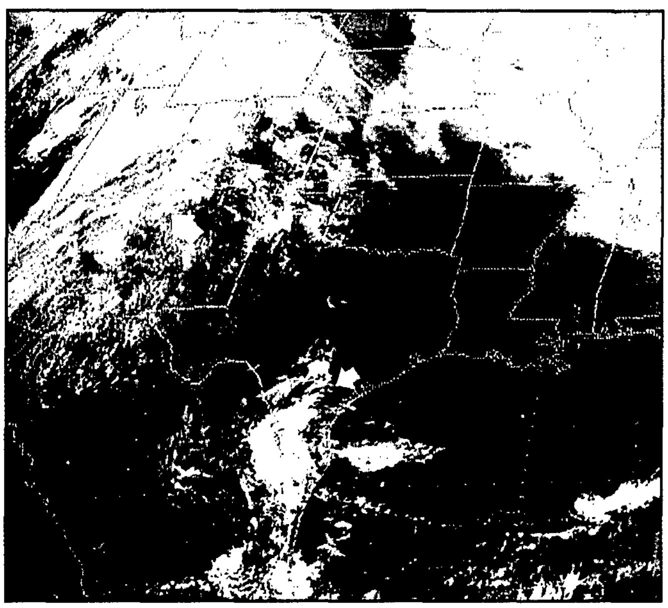

Figure 4-90a. GOES-E VIS, 2046Z/ 6 February 1980
Northward moisture advection from the Gulf of Mexico.

In the following event, a winter storm moved across the Great Basin region as shown in the surface chart, Figure 4-91. The 500 mb and 300 mb charts are respectively shown in Figure 4-92 and 4-93. The IR photo, Figure 4-94, reveals a pronounced polar jet over the lower two-thirds of the CONUS and confirms the 300 mb jet stream's location. The approaching short wave comma can be seen over the western CONUS. Pacific moisture had spread eastward over the shallow cP air mass and snow developed across the Northern Plains many hours prior to the arrival of the primary low-pressure system (Figure 4-91).

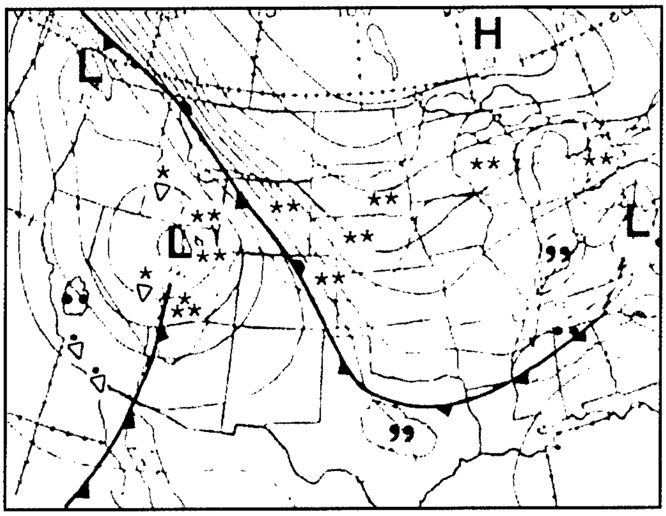

Figure 4-91. Surface, 1200Z/21 January 1982
North Pacific Low over Utah should remain intact over the mountains. Expect upper-level cyclogenesis over the Great Basin.

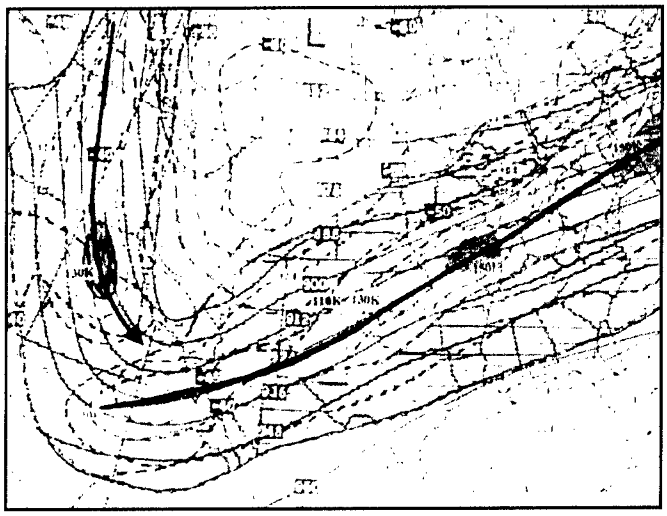

Figure 4-93. 300 mb, 1200Z/21 January 1982
Pronounced jet stream across the CONUS. Jet digging southward off the West Coast.

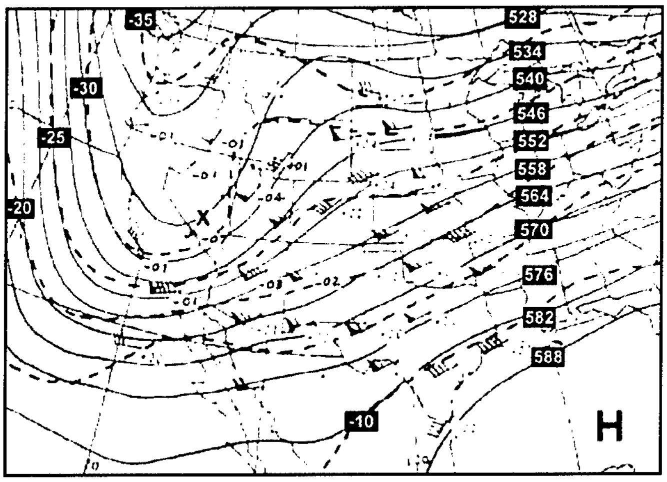

Figure 4-92. 500 mb, 1200Z/21 January 1982
90 knot jet max at the base of West Coast trough. Wide spacing of contours over northern California and Nevada suggest cyclogenesis.

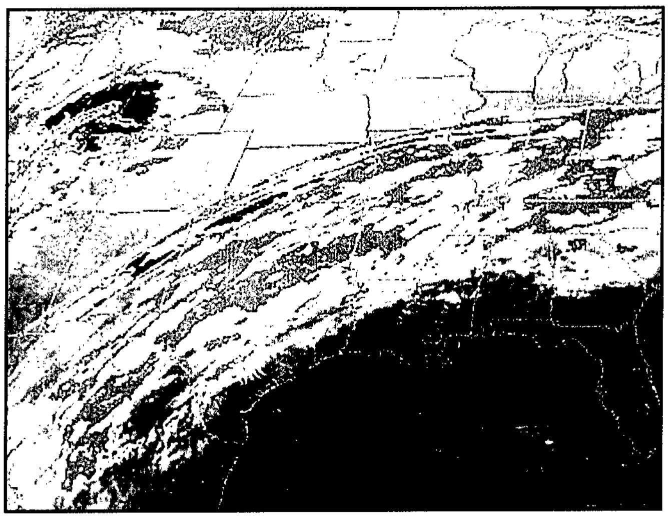

Figure 4-94. GOES-E IR, 0900Z/ 21 January 1982
Extensive jet stream cirrus shown over the southern CONUS. Short wave comma cloud system shown over the western CONUS.

In Figure 4-95 (24 hours later), widespread precipitation had developed as Gulf moisture overran the polar boundary across the Southern Plains. Additionally, the arrival of PVA, vertical motion and Pacific moisture over the central and southern Rockies had increased precipitation. Figure 4-96 shows the rapid 500 mb short wave trough progression. A major winter storm developed with a severe ice storm over the central Great Plains as shown in Figure 4-95. Moderate to heavy snow fell over the northern Great Plains. A severe thunderstorm outbreak occurred over central Kansas and Oklahoma, which was associated with the vorticity comma cloud shown in Figure 4-97. Figure 4-98 shows the occluded storm over the Great Lakes 24 hours later.

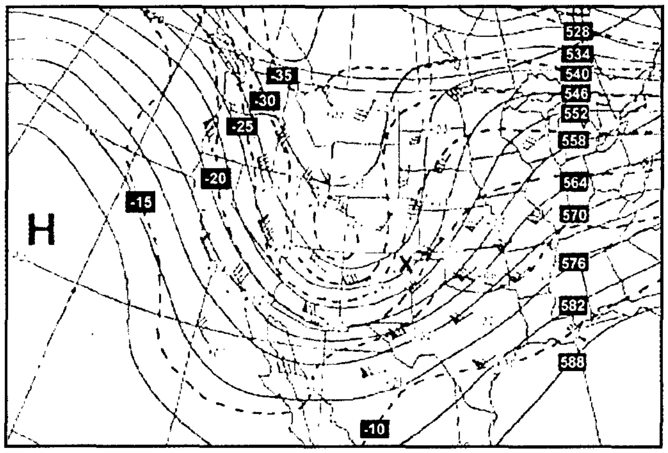

Figure 4-96. 500 mb, 1200Z/22 January 1982
24 hours later than Figure 4-92, a cold pocket had developed over Utah/Colorado. No 500 mb low had shown yet, but the low appeared over Nebraska 12-hours later (23/0000Z).

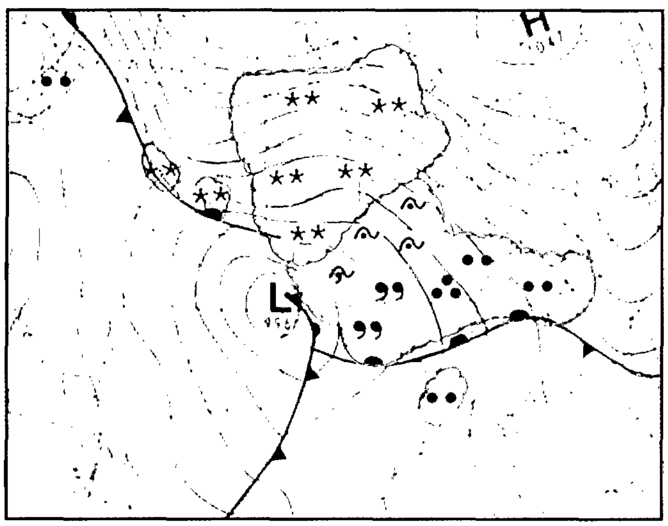

Figure 4-95. Surface, 1200Z/22 January 1982
24 hours later than Figure 4-91, the storm lifted northeastward when it moved out of the central Rockies.

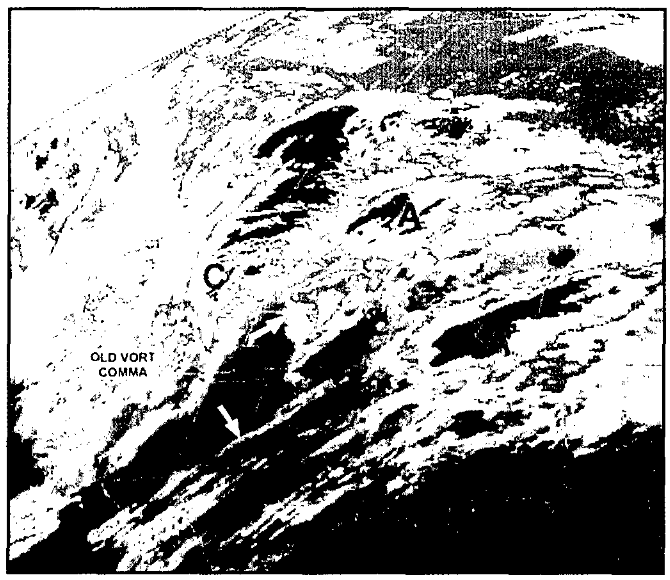

Figure 4-97. GOES-E IR, 1030Z/ 22 January 1982
Severe thunderstorms developed within the vorticity comma cloud noted by "**B**".

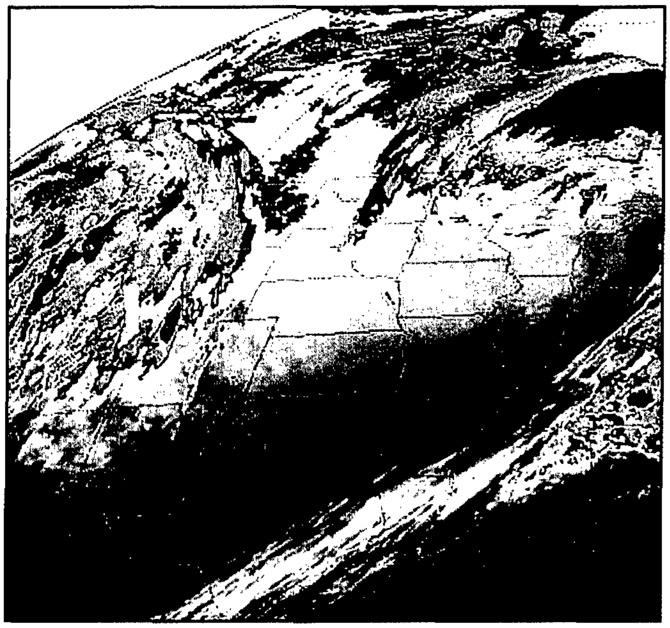

Figure 4-98. GOES-E IR, 1200Z/ 23 January 1982
24 hours later than Figure 4-97, the storm system organized over the Central Plains and moved rapidly northeastward.

The following example is included to advise central and northern Midwestern forecasters to pay attention to low pressure systems that are moving across Arizona and New Mexico when a long wave trough exists over the Rocky Mountains. The central and eastern CONUS are often under stationary polar air. Western CONUS short waves move eastward over Arizona and New Mexico, bottom out (recurved) over western Texas and lift northeastward across the Great Plains. Since the Midwest is under the dominance of cP air, the polar frontal boundary lies across southern Texas and eastward along the Gulf Coast. Frontal cyclogenesis occurs over Texas and/or Louisiana as the approaching short wave lifts northward. This is a heavy snow event for the central and northern Great Plains because these areas are under cold air. A long wave trough must exist over the western High Plains and Rocky Mountains so that short waves moving through the long wave are able to recurve northeastward. Gulf moisture advects northward ahead of the developing storm and increases the probability of heavy snowfall. In this event a series of low-latitude storms tracked across the central CONUS because of the location of the long wave trough. Figures 4-99 through 4-103 depict the surface pattern 24 hours before, during main low development and 24 hours later. In Figure 4-99, the mP frontal system and associated North Pacific Low is shown over the Colorado Plateau region. The stationary front along the Texas Gulf Coast should be watched carefully; frontal waves often form along these fronts.

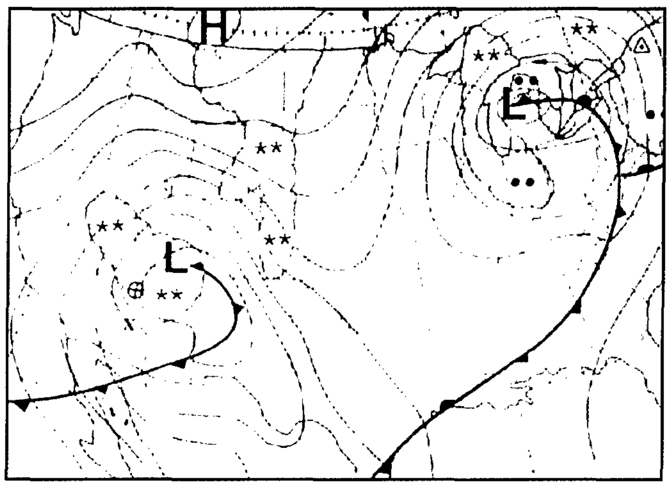

Figure 4-99. Day 1 Surface, 1200Z/ 20 February 1971

In Figure 4-100, 24 hours later, the mP surface front and low dissipated when they emerged from the Rockies. The remnants of the mP frontal system are reflected by the inverted troughing north of the frontal low (Texas Low) in eastern Texas. The approaching upper disturbance over western Texas sets off further development of the east Texas Low. Widespread overrunning snowfall is shown in Figure 4-100 occurring to the northwest of the low. The division line between rain and snow in Figure 4-100 over Oklahoma is along the projected 500 mb height fall center track (covered later in this chapter). By the next day, Figure 4-101, the Texas Low developed into a major storm system.

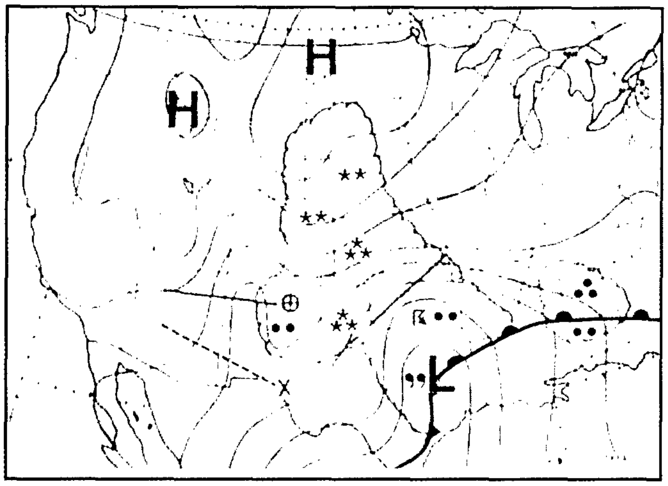

Figure 4-100. Day 2 Surface, 1200Z/ 21 February 1971

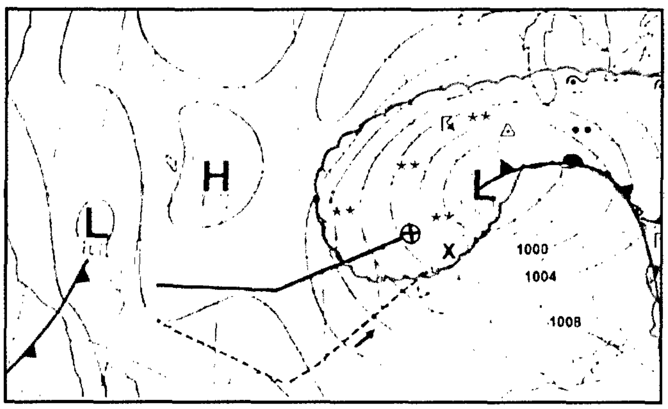

Figure 4-101. Day 3 Surface, 1200Z/ 22 February 1971

Snowfall of 15 to 25 inches fell over Iowa, Nebraska, Kansas and western Oklahoma.

Polar fronts will sometimes become stationary over the central Midwest when there are changes occurring in the upper levels. Generally, cP air over the central and northern Midwest becomes modified when warmer air erodes the polar air. In the following example, Figures 4-102 and 4-103 depict an example of frontal cyclogenesis that occurs over the southern Great Plains when a long wave trough is located over/west of the Rocky Mountains. Most of the central and upper Midwest is still affected by cP air. In Figure 4-102, a stationary front lies across the central Midwest. A short wave has just entered the West Coast; the long wave trough is stationary over the western CONUS. Twenty-fours later in Figure 4-103, the short wave trough has continued to deepen, and a closed low appears within the trough over northeastern New Mexico (shown by the cross-hair circle). Polar frontal cyclogenesis has developed; the primary low is the Texas Low in Oklahoma. Widespread precipitation has developed with moderate to heavy snow over the Western Plains.

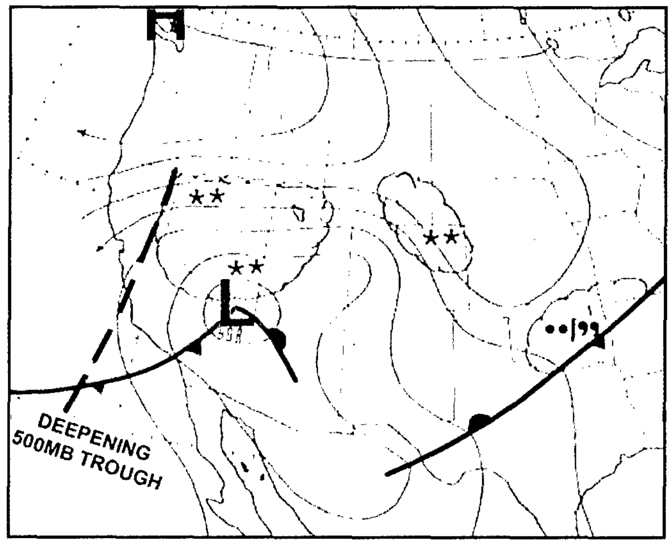

Figure 4-102. Day 1 Surface, 1200Z/ 2 January 1971

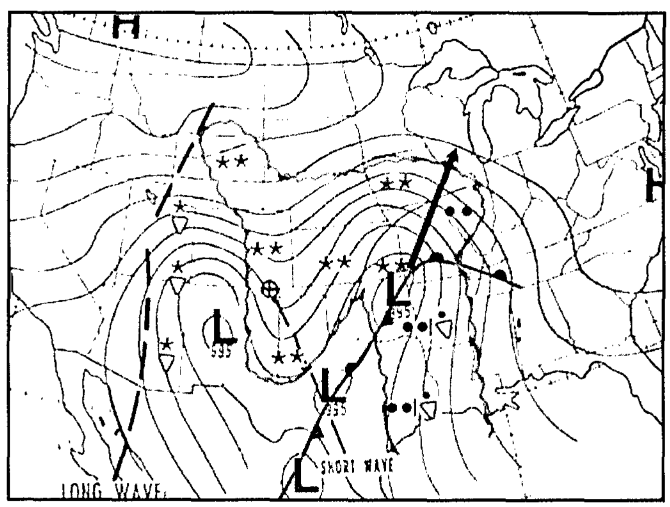

Figure 4-103. Day 2 Surface, 1200Z/ 2 January 1971

Prevailing High - Short Waves Systems (Zonal Flow)

As mentioned earlier, most precipitation events that occurred over the central and eastern CONUS are associated with a parade of short waves that do not slow down and undergo mid- and upper-level cyclogenesis. Often during January and February, polar ridges extend southward across the eastern two-thirds of the CONUS (east of the Rocky Mountains) and may persist for several days. Pacific short waves that move out of the mountains and overrun the stagnant cP ridge produce swaths of snowfall generally less than four inches. There may be a polar frontal boundary with a wave located over the southern CONUS.

Figures 4-104 through 4-106 depict an event. The NGM initial 500 mb heights/vorticity chart, Figure 4-104, shows several small short waves embedded within zonal flow. The PVA lobe over eastern Colorado and New Mexico reflects a short wave that produced a band of light snow over the central plain states. Figure 4-105 shows the forecast mid-level moisture that will spread over the Great Plains polar air mass. The surface/thickness panel, Figure 4-106, shows that a frontal boundary had formed over Kansas and Oklahoma as warmer air moved northward.

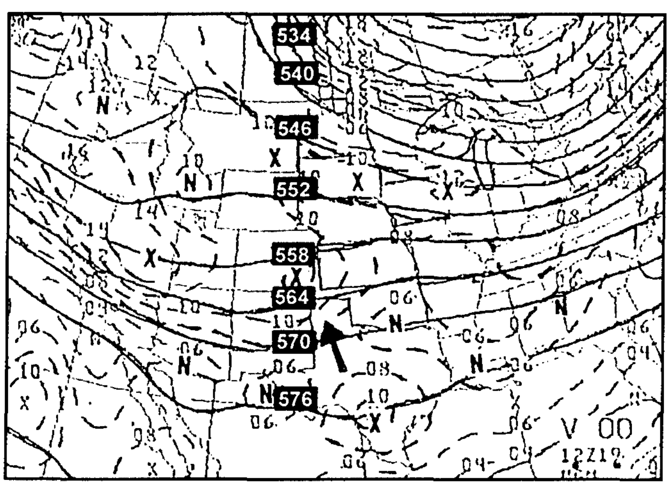

Figure 4-104. 500 mb Heights/Vorticity, 1200Z/ 19 February 1989

PVA lobes moving through zonal flow.

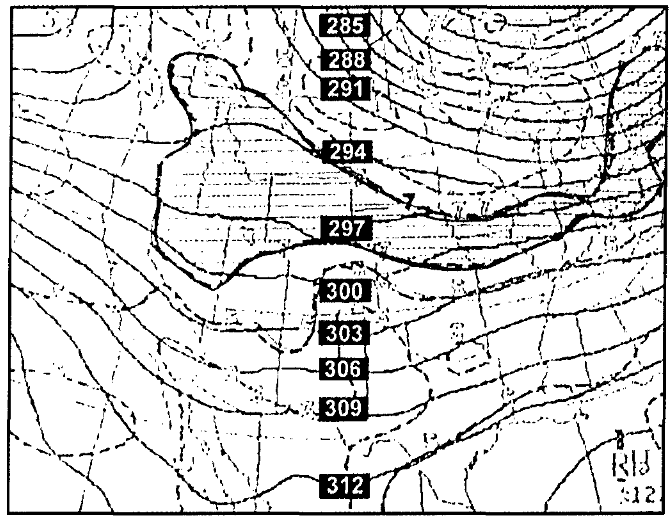

Figure 4-105. 700 mb HEIGHT/REL HUMIDITY, 1200Z/19 February 1989

Mid-level moisture (> 70% RH) overruns polar air.

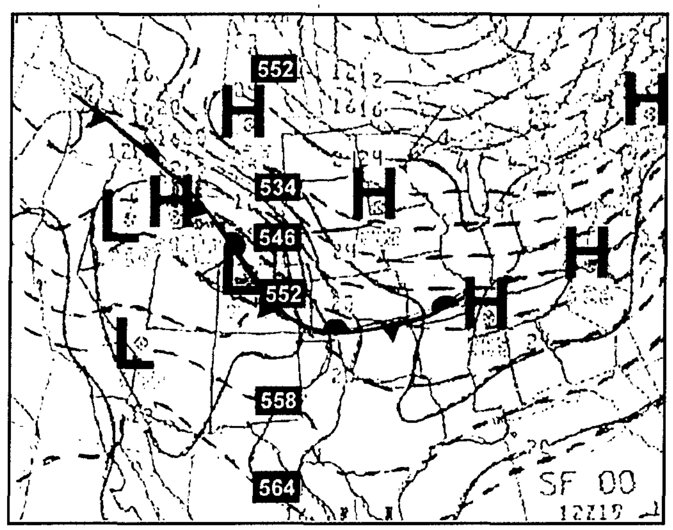

Figure 4-106. MSL PRES/1000-500 mb THKNS, 1200Z/19 February 1989

Polar air in place over eastern two-thirds of the CONUS. Boundary had developed over the Central Plains due to warm air advection.

A second event where a short wave overruns a polar air mass is depicted in Figures 4-107 through 4-110b. In this event, there was little evidence of a short wave if one looks for thermal or contour troughs in the upper air analyses (not shown). However, the impulse will appear within the vorticity isopleth field as noted by the dark arrows shown in Figures 4-107 and 4-109. Polar high prevails over the northern two-thirds of the CONUS as shown in Figures 4-108 and 4-110a. A series of short waves lifted northeastward from the long wave trough located over the southwestern CONUS. In Figure 4-107, the ETA analysis shows a PVA lobe entering western Kansas and Oklahoma (indicated by the arrow), however, there is no appreciable troughing within the contours.

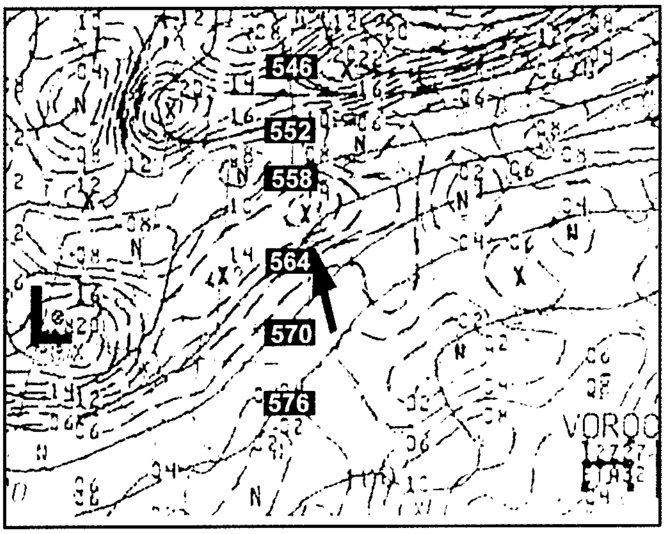

Figure 4-107. 500 mb HEIGHTS/VORTICITY, 1200Z/27 February 2001

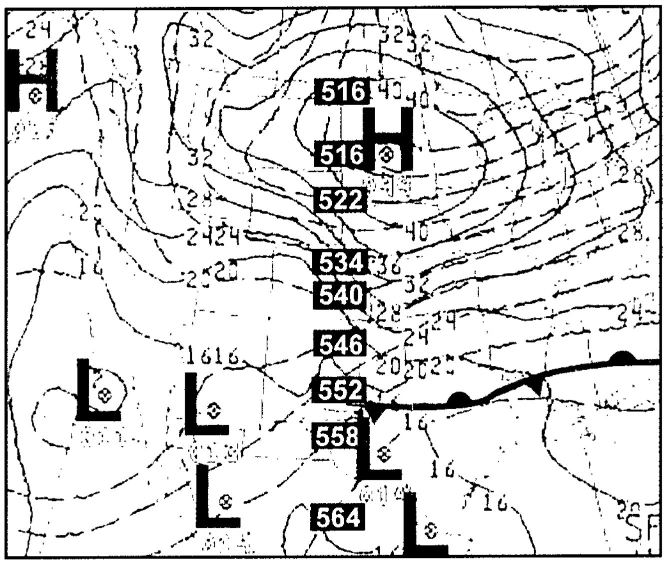

Figure 4-108. MSL PRES/1000-500 mb THKNS, 1200Z/27 February 2001

In Figures 4-109 and 4-110a, the polar front lies across the southern CONUS, yet, significant snow fell well to the north of the front—an excellent example of overrunning. In Figure 4-109, the ETA 12-hour forecast shows the PVA lobe over Kansas, Missouri and southern Nebraska as marked by the arrow. The initial and 12-hour 700 mb RH panels showed good moisture accompanying the short wave (not shown). Two to four with upwards to 6 inches of snow fell over northern Kansas and Missouri and southern Nebraska (somewhat of a surprise for the amount of snow that fell).

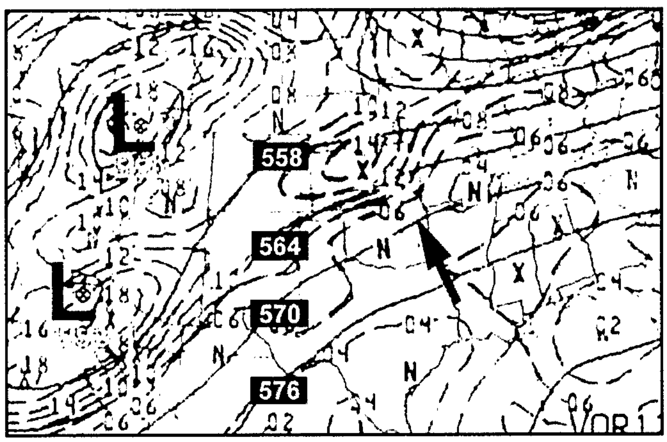

Figure 4-109. 12HR 500 mb HEIGHTS/VORTICITY, 0000Z/28 February 2001

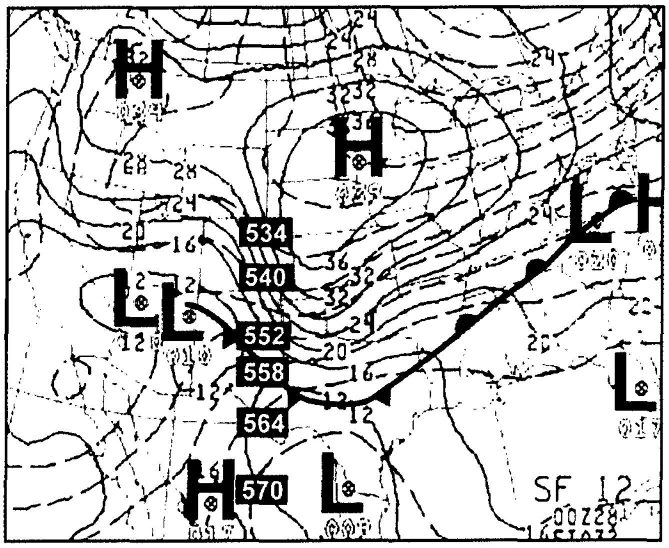

Figure 4-110a. 12 HR MSL PRES/1000-500 mb THKNS, 0000Z/28 February 2001

The 850 mb analysis is included (Figure 4-110b) to illustrate that frontal lows often appear at the 850 mb level above the shallow cold dome. Note the cold air advection into the western Central and Southern Plains.

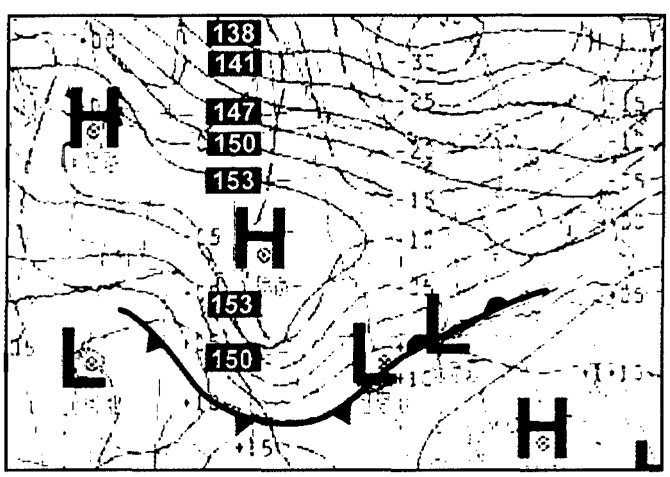

Figure 4-110b. 12HR 850 mb HEIGHTS/ TEMPS, 0000Z/28 February 2001

In another event shown in Figure 4-111, a narrow swath of heavy snow, marked by the arrows, occurred from the Texas Panhandle to northern Illinois when a small short wave moved over polar air 24 hours earlier. Another short wave appears over the Dakotas and eastern Nebraska in Figure 4-111.

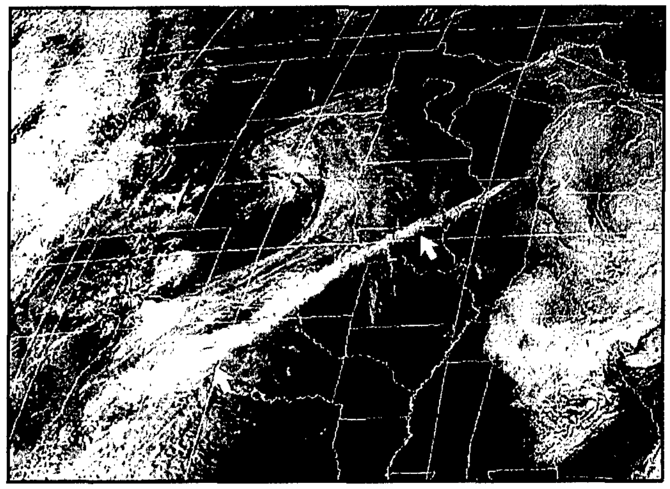

Figure 4-111. GOES-E VIS, 1932Z/ 6 December 1999

Figure 4-112 shows another narrow snowfall event over eastern Colorado and southern Nebraska. The region was under a stationary polar air mass. A short wave overran the polar air and deposited a band of snow as shown in the photo. In many of these events the snow area is wider east of the Rockies but tapers off to a narrow band as the short wave move eastward (due to increasingly drier air).

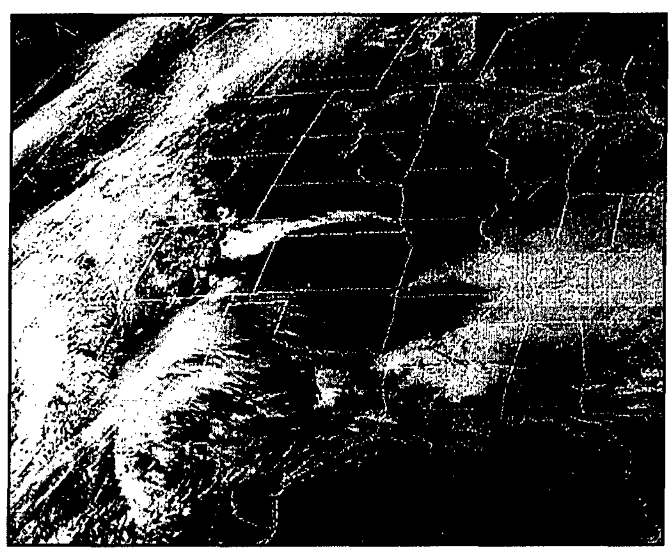

Figure 4-112. GOES-E VIS, 2130Z/ 5 March 1981

Cyclogenesis over the Central and Southern Great Plains - Inverted Troughs

Inverted trough systems, generally located over the central and southern CONUS during the winter, often produced extensive areas of low ceilings and considerable precipitation as shown in Figures 4-113 and. 4-114. The central and northern CONUS are under Canadian cP air. The polar frontal boundary lies stationary across the southern CONUS. Inverted troughs appear north of the polar front, usually associated with a frontal wave. Inverted troughs sometimes appear on surface analysis from fronts that have weakened as they move out of the Rockies (Figure 4-113). Also, non-frontal inverted troughs occur when there is an increase in discontinuities between two air masses (i.e., modified cP on the west and increased mT air on the east side of the trough). These systems are slow-movers. The precipitation from these surface inverted troughs may surprise Midwestern forecasters since there is no apparent surface front (west of their location) upon which to base a forecast. Moderate to heavy rain and snow is likely. When an upper-level system approaches the inverted trough, generally from the west,) then frontogenesis and perhaps, cyclogenesis will occur.

In Figure 4-113, moderate to heavy precipitation occurred within the inverted trough. A strong moist Gulf flow into the system attributed to the moderate to heavy snowfall from Missouri and Kansas and northward. The upper-level support for cyclogenesis within the inverted trough is shown over the western Great Plains. Black dashed lines mark the upper-level trough's position.

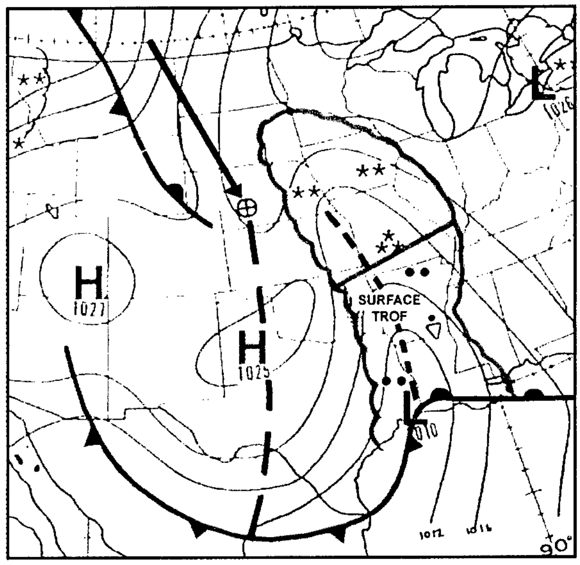

Figure 4-113. Surface, 1200Z/ 26 November 1975

Another example is shown in Figure 4-114. Most of the nation is under a cP air mass. Inverted isobars extend northward into the central Great Plains. An extensive area of snow is shown on either side of the trough. The upper system appeared over New Mexico. Occasionally, surface cyclogenesis will occur further to the north within the inverted trough rather than along the stationary polar front. This will occur when a short wave recurves northeastward over the Southern Plains.

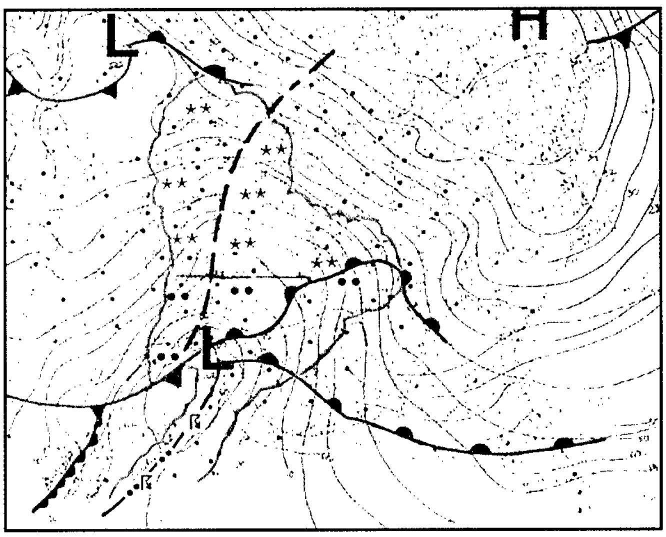

Figure 4-114. Surface, 2100Z/January 1994
A major snowstorm evolved within 24 hours over the eastern CONUS.

500 mb Height Fall Centers and Developing Winter Storms

A strong correlation between the magnitude of the 500 mb height fall centers (HFCs) and their tracks and the development, intensification, and the path of storm systems at the surface was found to exist and is now called the Weber Technique. Also, closely following the track of the HFC could be quite helpful in the determination of where heavy snowfall would most likely to occur. There are many excellent forecasting rules available to determine the potential for snow versus rain and amounts. The information to be presented here is general and will give an idea where the significant snow area will be located in relation to the storm system. These rules were developed from many cases of Midwest snowstorms.

As a general rule, the division line between frozen and liquid precipitation is the track of the HFC (and positive vorticity center) that often lies along the 1000-500 mb 540-thickness contour. Snow occurs to the left (cold air side) of these tracks. This rule does not include light snow showers and flurries that would develop within cold air advection following passage of the low and cold front. The HFC is often shown ahead of the main positive vorticity center, and will often show if the storm is lifting northward or digging southward. Figures 4-115 through 4-117 depict various relationships between 500 mb lows, surface lows, and 500 mb HFC tracks and significant snowfall using the Weber Technique.

Another general rule: Often precipitation is already occurring over the Plains before the arrival of the upper-level system. It has been found that in prevailing high events (discussed more in detail later in this chapter), locating the rain/snow division line on surface charts would be the future track of the height fall center (typically the 540 thickness isopleth).

As shown in Figure 4-115, when the surface low is to the left of the 500 mb HFC track, the significant snowfall area will lie approximately parallel to and to the left of either the surface low track or the 500 mb low track depending on how cold the storm system is. In nearly all cases, the snowfall area will at least lie along and parallel to the 500 mb low track. The surface low and 500 mb HFC center track alignment is typically seen when there is an absence of a strong surface high pressure system over the central and upper Midwest (i.e., receding surface high pressure pattern).

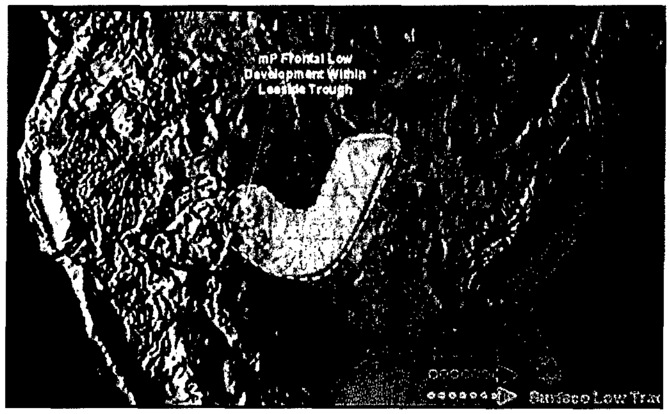

Figure 4-115. Heavy Snow with Surface Low Left of HFC Track

In Figure 4-116 when the surface low is to the right of the 500 mb HFC track, the significant snowfall area will lie approximately parallel to and to the left of the 500 mb HFC track. The surface low and 500 mb HFC track alignment is typically seen when a strong surface high pressure system is present over the central and upper Midwest (i.e., prevailing surface high pressure pattern). The associated surface low pressure system is often several hundred miles east of the its upper support. Liquid precipitation would occur from the frontal disturbance to the HFC/vorticity center tracks.

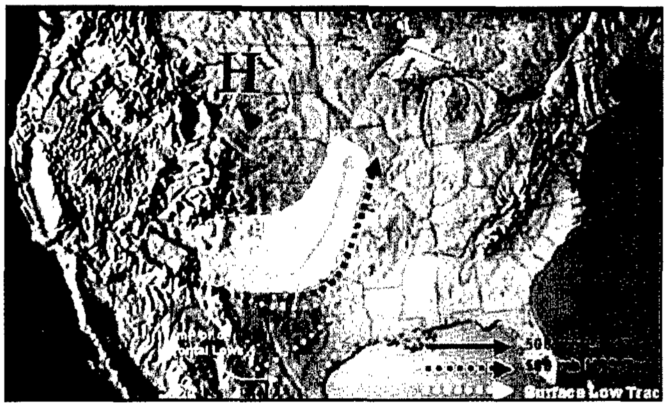

Figure 4-116. Heavy Snow with Surface Low Right of HFC Track

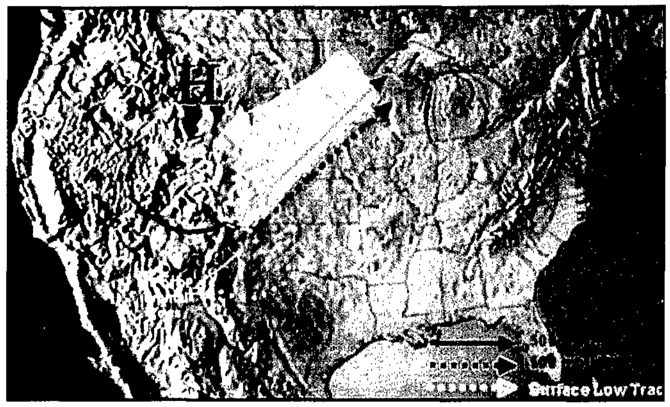

Figure 4-117. Heavy Snow Northwest of HFC Track

The alignment of tracks shown in Figure 4-117 is similar to Figure 4-116. This pattern is presented because it does occur over the central and western CONUS and accounts for the majority of snow forecast misses. In these patterns, a long wave trough lies over the western CONUS. Short waves move through the long wave, bottom out (recurve) over the Colorado Plateau/southern Rockies region, and lift northeastward across the western Great Plains. At the surface, there is usually a stationary mP or a modified stationary cP front lying northeast-southwest across the Midwest. Main low development is along the front. With colder air to the north within the surface ridge, as shown in Figure 4-117, the snowfall path will usually fall along and to the northwest of the height fall track rather than along the main surface low track.

To clarify the model shown in Figure 4-117 above, an actual event that occurred a few years ago will now be shown. In Figure 4-118, the primary surface low (Texas Low) is located over north-central Texas and not Colorado. The low and inverted trough pattern over Colorado is a reflection of the upper low and should not move eastward, but instead, fill. However, the heavy snow area is occurring within the Colorado Low because of the approaching 500 mb low, PVA and moisture, and, in addition, the low-level easterly upslope flow over the Western Plains to the Rocky Mountains. The 04/1200Z height fall and vorticity centers over New Mexico in Figure 4-118 are nearing the frontal system. By nine hours later (Figure 4-119), the main surface low has organized (deepened) over Illinois while the Colorado Low has filled. The heavy snowfall area still remains well behind (northwest) the low in Illinois. It is not recommended that the snow to be forecast to progress eastward behind the surface low when the upper system is a great distance away and is continuing to move northeasterly. In this case, the heavy snow moved into the eastern Dakotas and Minnesota and left eastern Nebraska, Kansas and southern Iowa without significant snowfall, i.e., the snow area remained along and to the left of the 500 mb height fall center track.

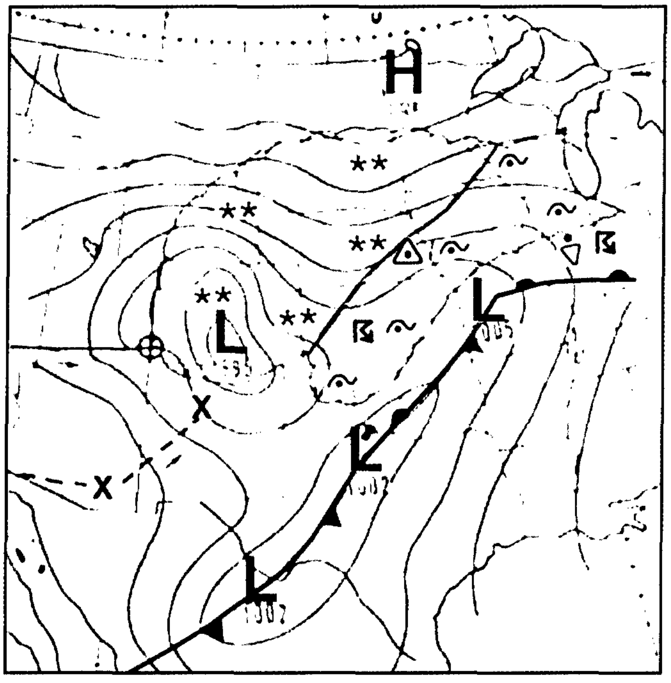

Figure 4-118. Surface, 1500Z/4 March 1976

A case study with conventional and satellite data will now be presented. This system is typical of the evolution of storms that emerge from the Rocky Mountains and "get their act together" over the Great Plains. In Figures 4-120 and 4-121, a split-flow low is shown over the Great Basin region. This low developed within the short wave trough over western Nevada twelve hours earlier. The polar jet is aligned west to east, which suggest the disturbance will continue eastward. As is in many Central Plains storm systems, the polar jet will begin to move northward on the front side of the deepening short wave. This northward movement of the jet forces the storm to lift northward. This is a very important rule. The models sometimes still have a problem forecasting the track of these developing Rocky Mountain storms due to the rapid increased of warm air, moisture and PVA that exists over the central CONUS.

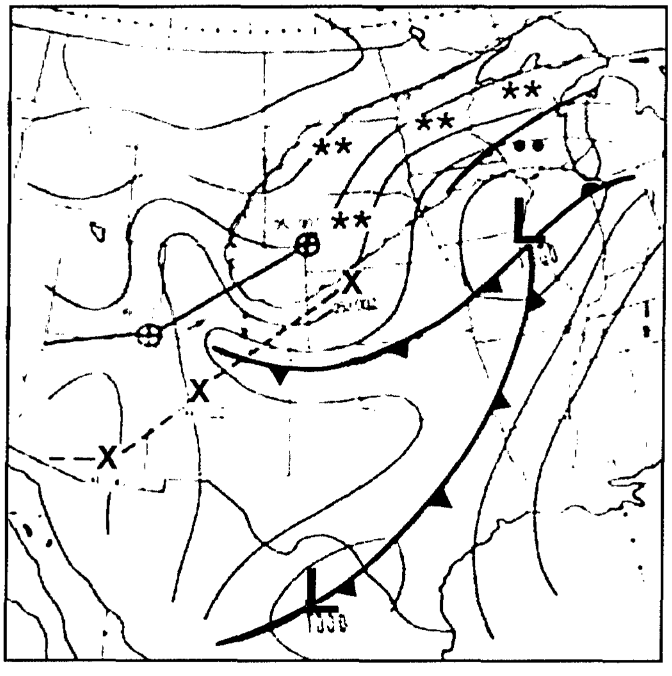

Figure 4-119. Surface, 0000Z/5 March 1976

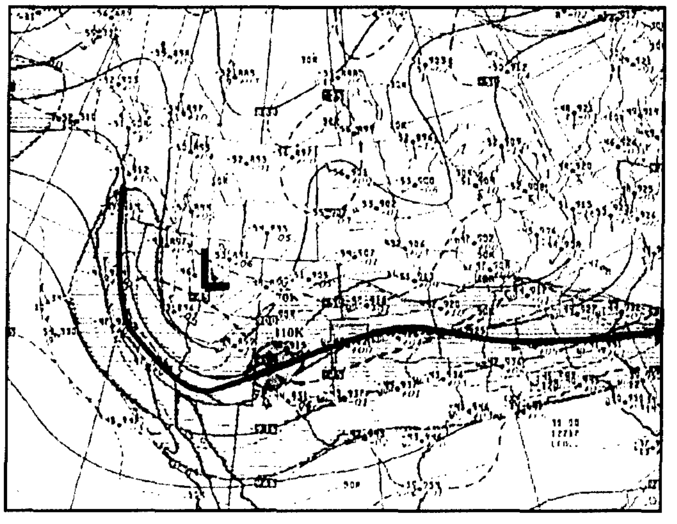

Figure 4-120. 300 mb, 1200Z/17 February 1984

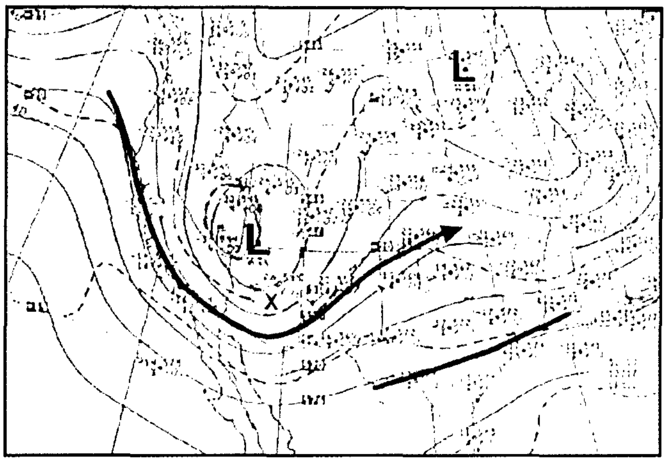

Figure 4-121. 500 mb, 1200Z/17 February 1984

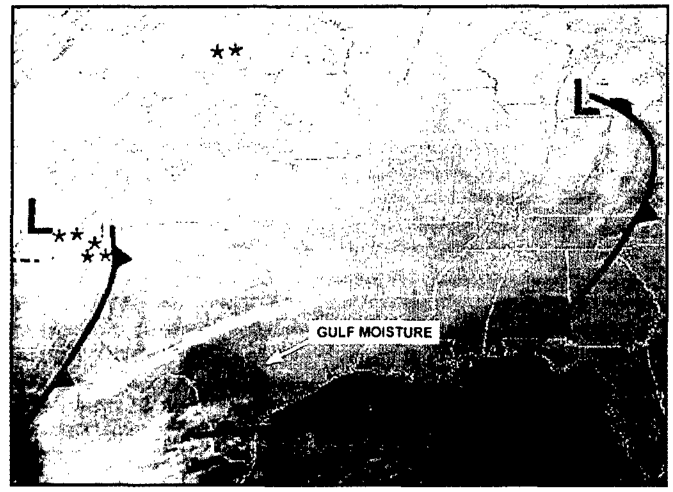

Figure 4-123. GOES-E IR, 1230Z/ 17 February 1984

Figures 4-122 and 4-123, respectively, depict the surface and satellite information. At the surface in Figure 4-122, a well-defined low-pressure system did not become disorganized while moving across the mountains. At this point, Midwestern forecasters would most likely expect a significant storm to occur over their region. The satellite image, Figure 4-123, reveals an ill-defined comma cloud system over the western CONUS. The white arrow marks Gulf moisture advection over southern Texas. Advection should continue northward ahead of the storm.

In Figure 4-124, the inset (shown in the satellite photo below) reveals the 500 mb data approximately nine hours later than the satellite image. The 500 mb data depicts a typical closed split-flow low that should have a well-defined cloud systems associated with it. Yet, a disorganize cloud system extends over a large area of the western CONUS. Within 24 hours, a well-define comma cloud system will be located over the Great Plains.

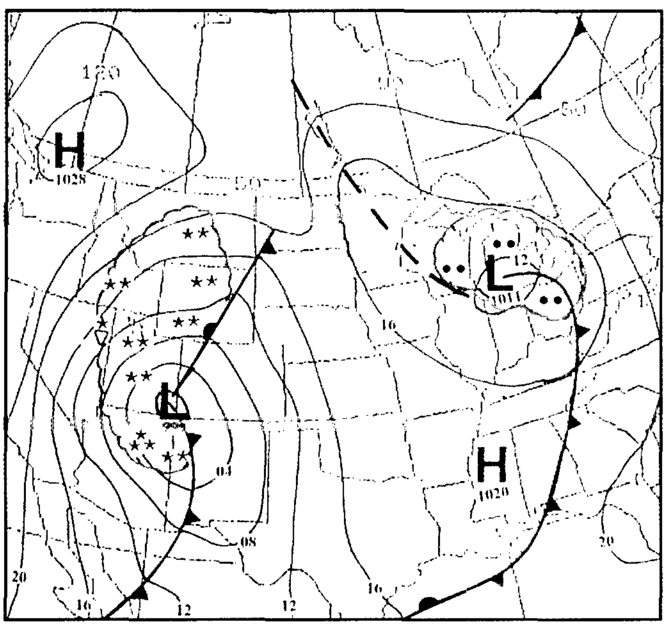

Figure 4-122. Surface, 1200Z/17 February 1984

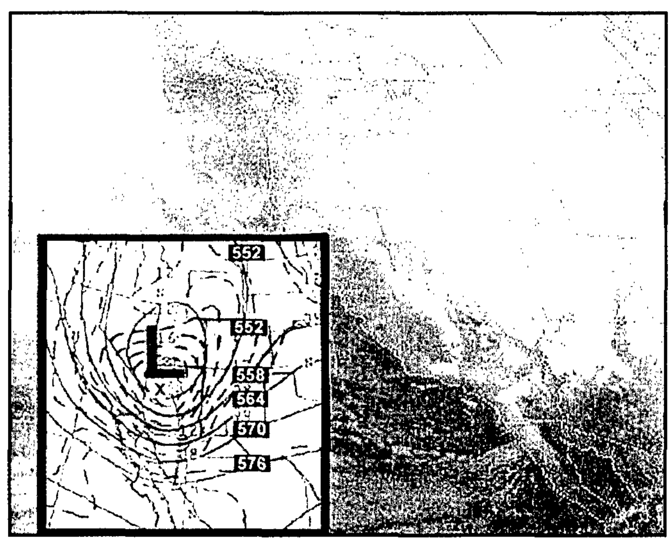

Figure 4-124. GOES-W IR, 0346Z/ 17 February 1984
Inset: 500 mb HEIGHTS/VORTICITY, 1200Z/17 February 1984

The next 12-hour data set is shown in Figure 4-125 through 4-128. In Figures 4-125 and 4-126, the upper low has moved into Colorado. The polar jet is lifting northward over the Great Plains. Mid and upper-level difluent flow ahead of the low will enhance clouds and precipitation over the Central Plains and eastward.

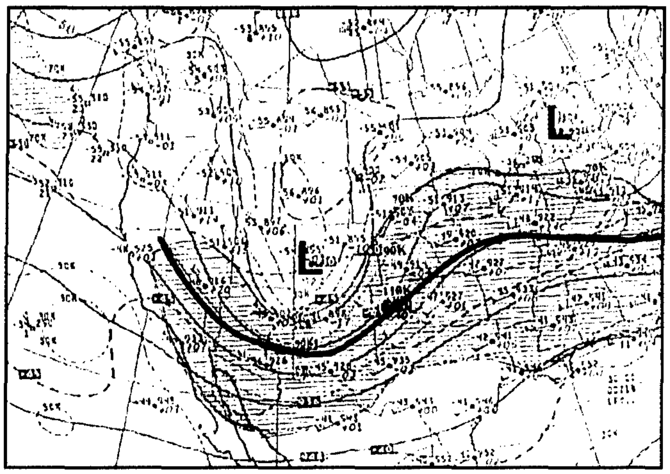

Figure 4-125. 300 mb, 0000Z/18 February 1984

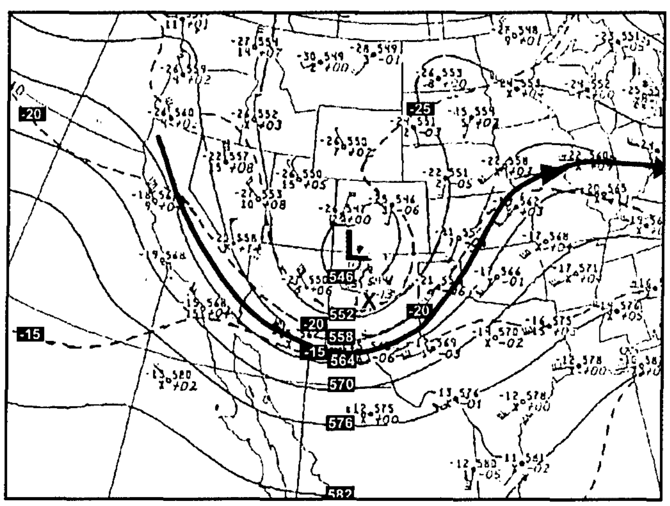

Figure 4-126. 500 mb, 0000Z/18 February 1984

At the surface, (Figure 4-127), the low has moved into the Texas Panhandle. The accompany snowfall area has increased over the Colorado and Wyoming Rockies. The visible satellite photo shown in the inset is three hours earlier and shows Gulf moisture advection over the Southern Plains (marked by the white arrow). The IR photo, Figure 4-128, still shows a disorganized cloud system associated with the short wave. The bolder low (**L**) represents the 500 mb low. The thinner **L** is the surface low position. The **X** is the height fall center at the time of the chart. The dashed line is the track of the height fall centers. These features will be shown on subsequent satellite photos. No model guidance was saved.

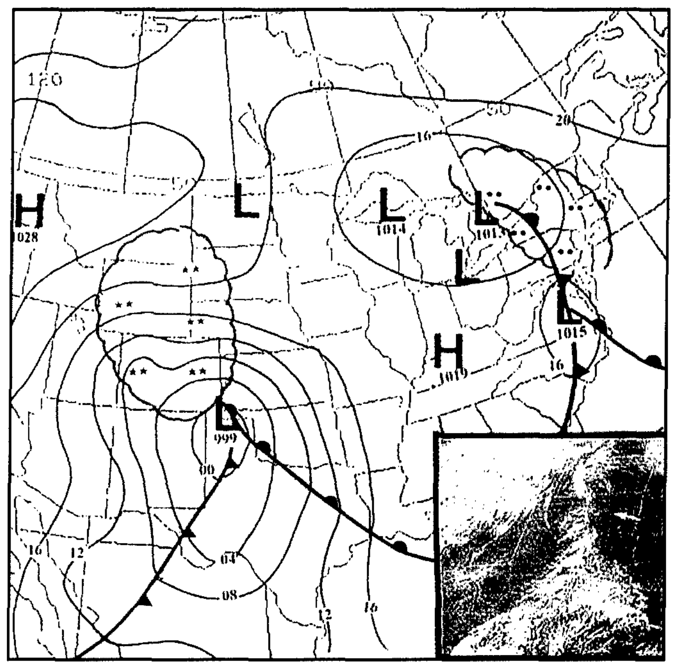

Figure 4-127. Surface 0000Z/18 February 1984
Inset: GOES-E VIS, 2130Z/17 February 1984. The inset shows Gulf moisture advection.

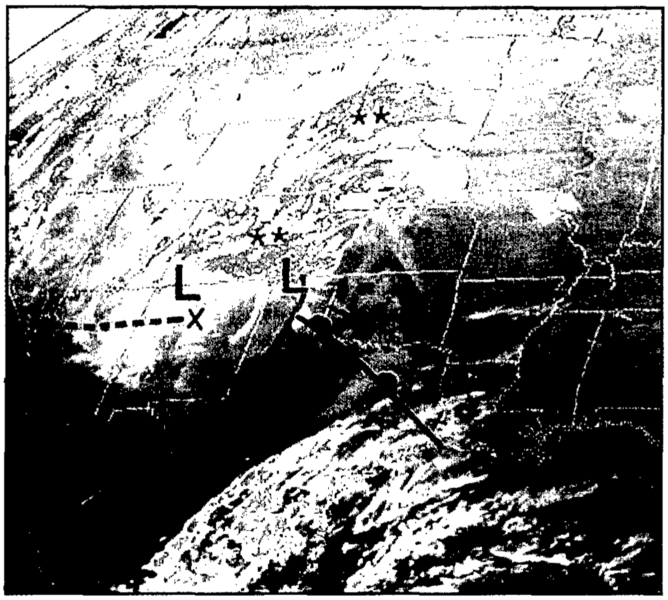

Figure 4-128. GOES-E IR, 0000Z/ 18 February 1984

Frontal placements from the NWS surface chart.

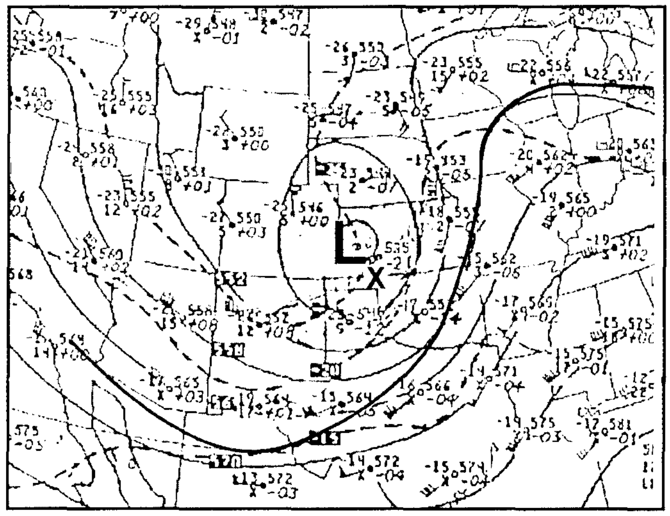

Figure 4-130. 500 mb, 1200Z/18 February 1984

Twelve hours later, Figures 4-129 and 4-130, the upper low has slowed down over Colorado as it intensifies. Also, deceleration often indicates that the system may turn northward. The polar jet has now aligned south to north (Figure 4-129); therefore, the storm should turn northward. An empirical rule regarding the magnitude of 12-hour height fall centers and their tracks, helpful to determine system movement, is covered later in this section.

A well-defined storm system with moderate to heavy snowfall is shown in Figure 4-131. Positive vorticity advection and the introduction of Gulf moisture into the system have increased the precipitation areas. The IR photo, Figure 4-132, illustrates a well-defined comma system. Rain and thunderstorms are occurring over the Iowa-Illinois region (within the vorticity comma cloud—see Figure 4-85). Moderate to heavy snow is associated with the deformation zone cloud system. The heavier snowfall is along the southern side of the deformation cloud system as shown in Figure 4-132.

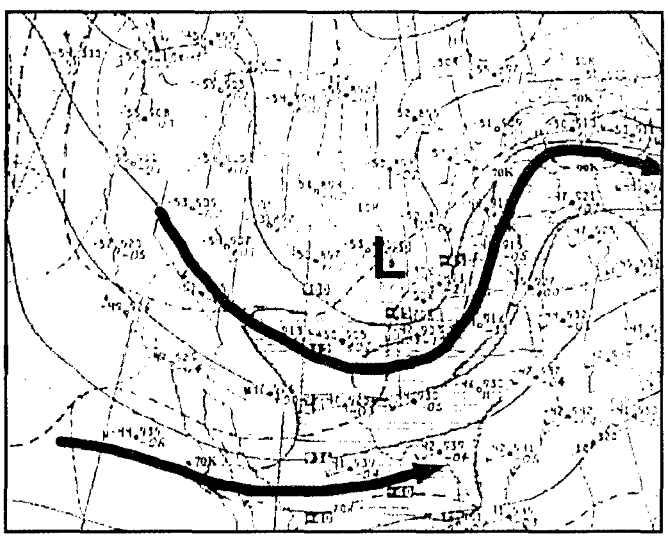

Figure 4-129. 300 mb, 1200Z/18 February 1984

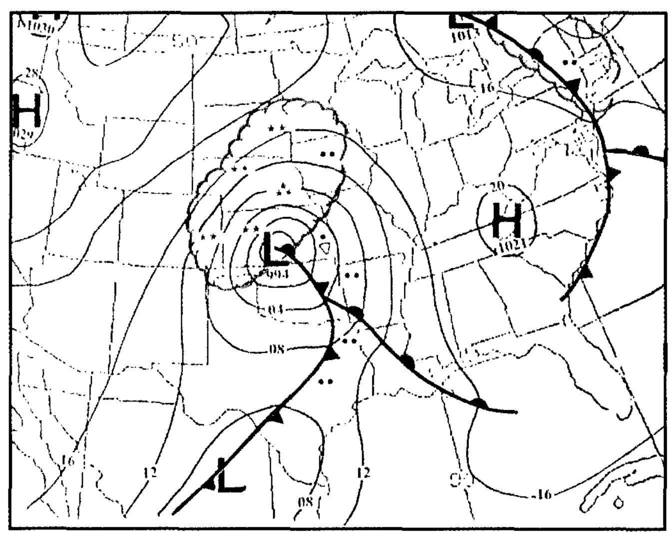

Figure 4-131. Surface, 1200Z/18 February 1984

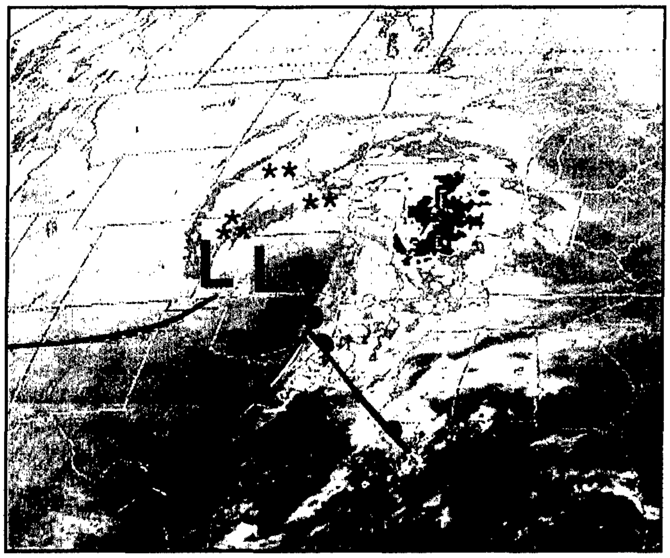

Figure 4-132. GOES-E IR, 1230Z/ 18 February 1984

The last set in this series is shown in Figures 4-133 through 4-136. In Figure 4-133, the upper low is moving northeastward across eastern Nebraska; a jet maximum appears over the southern/southeastern sector of the storm (Oklahoma into southeastern Missouri), which is often the typical location for wind maxima within these occluded systems. In Figure 4-134, the height fall center moved from southwestern Kansas to northeastern Missouri during the past 12-hours.

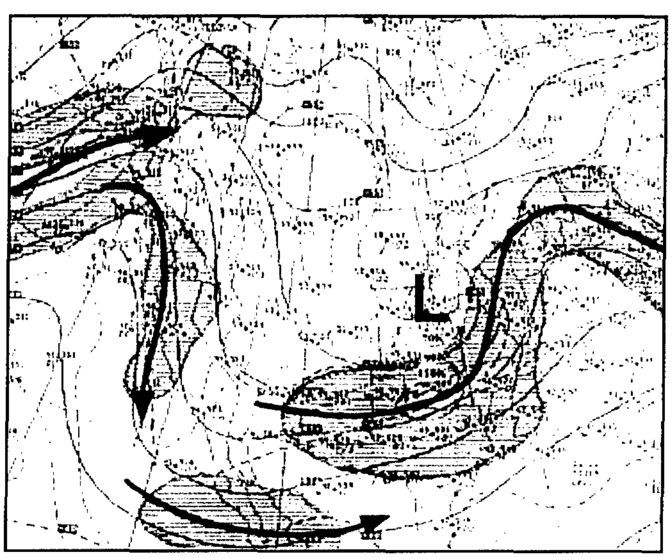

Figure 4-133. 300 mb, 0000Z/19 February 1984

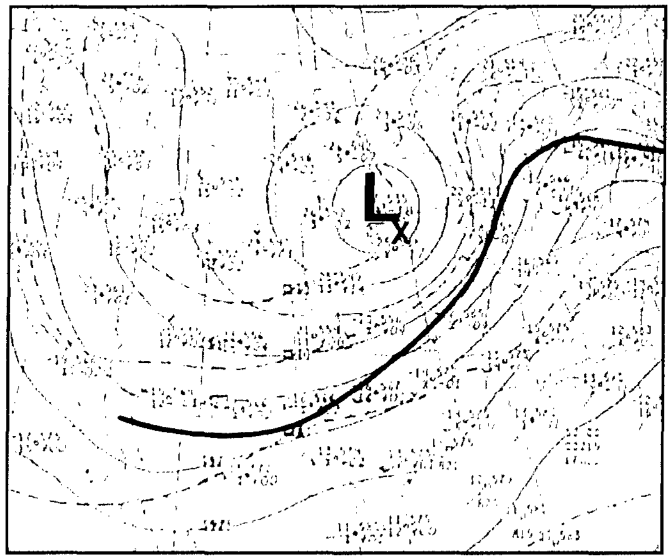

Figure 4-134. 500 mb, 0000Z/19 February 1984

The storm continues northeastward; moderate to heavy snow is occurring over eastern Nebraska northward into the Dakotas and Minnesota (Figure 4-135). This snow area aligns with the pronounced deformation cloud system shown in Figure 4-136. In Figure 4-136, storm recurvature is evident by the height falls track (red and white dashed line).

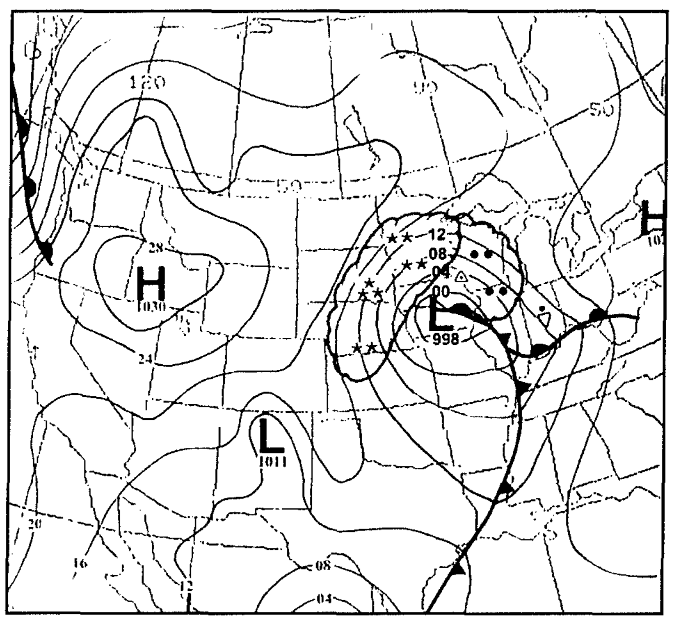

Figure 4-135. Surface, 0000Z/19 February 1984

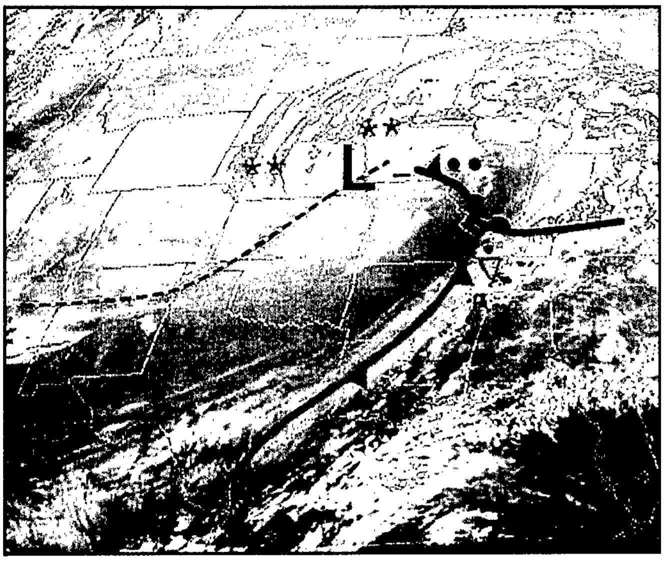

Figure 4-136. GOES-E IR, 0030Z/
19 February 1984

In summary, the following satellite sequence, Figures 4-137a through 137d, shows how rapid a positive vorticity comma cloud system can evolve and become organize once it is free of mountain influences. The sequence is over a six-hour period.

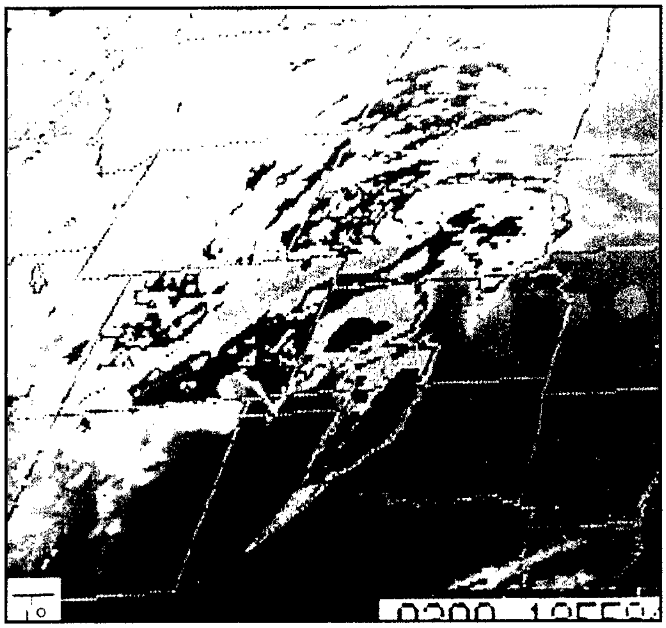

Figure 4-137b. GOES-E IR, 0200Z/
18 February 1984

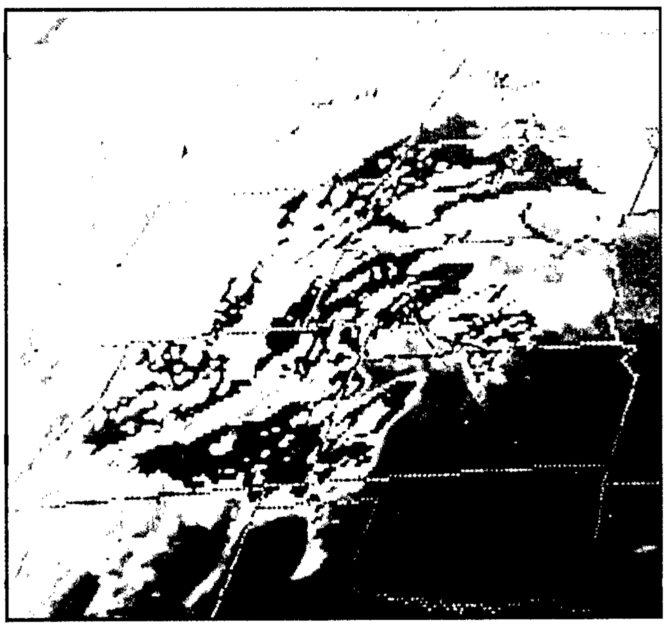

Figure 4-137a. GOES-E IR, 0000Z/
18 February 1984

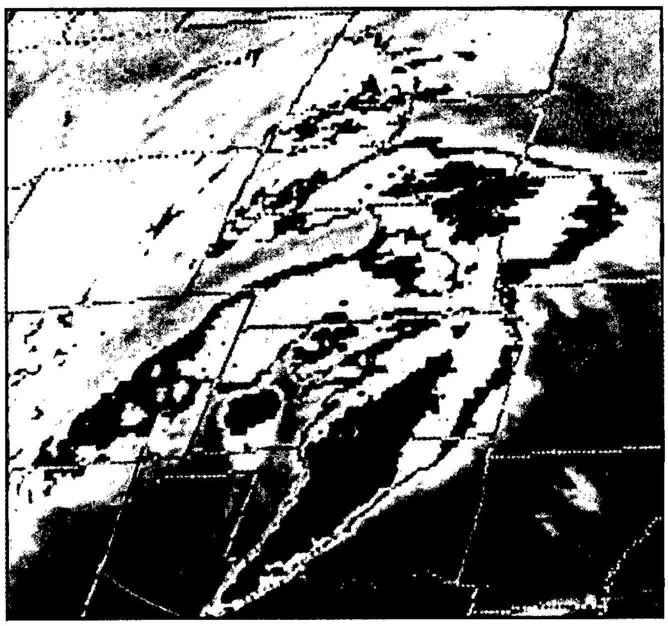

Figure 4-137c. GOES-E IR, 0400Z/
18 February 1984

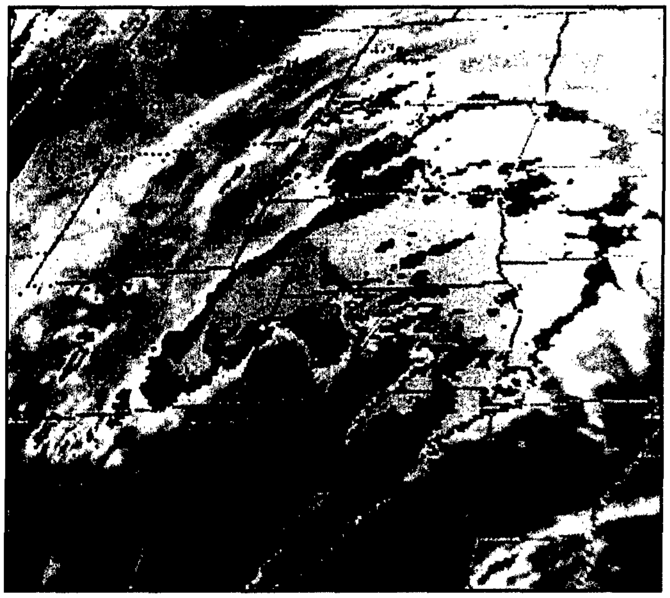

Figure 4-137d. GOES-E, IR, 0600Z/18 February 1984

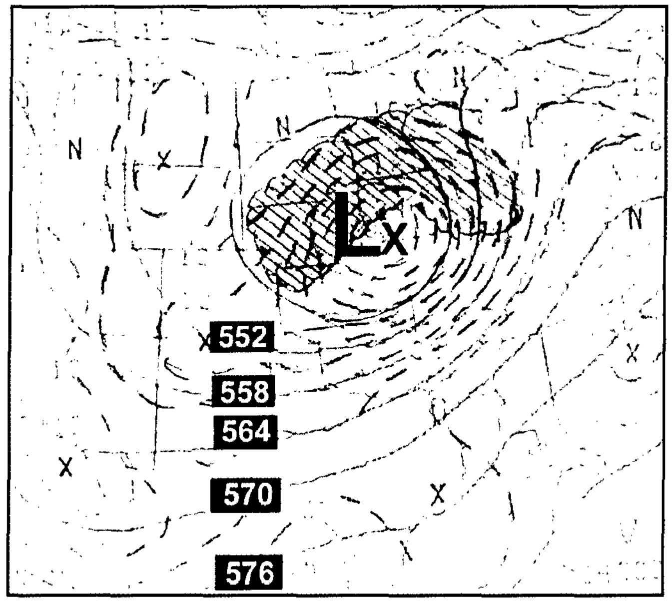

Figure 4-138. 00HR 500 mb HEIGHTS/VORTICITY, 0000Z/19 February 1984

Comma cloud systems appear in all sizes; they are associated with PVA maxima. A large variety of shapes are associated with PVA patterns depending on the development of the vorticity pattern. In large-scale, midlatitude cyclones such as shown east of the Rocky Mountains, the structures of the three primary cloud systems are generally recognizable. It is important for forecasters to analyze for the developing deformation zone on the numerical model's initial and forecast periods. In Figure 4-138, the initial 500 mb heights/vorticity chart depicts a drawn hatched area where clouds and precipitation would occur (the deformation zone, colored as purple in Figure 4-138, would likely be the area of significant snowfall). The vorticity center shown in Figure 4-138 (**X**) is a short distance from the height fall center track shown in Figure 4-139.

Figure 4-139. GOES-E IR, 0030Z/ 19 February 1984

Figure 4-140 shows the two-day snow accumulations with this storm system. In the figure, the dashed line represents the height fall center track (and the 540 thickness). No snowfall accumulations were reported to the right of the track.

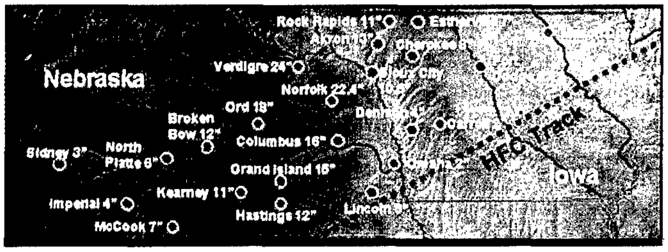

Figure 4-140. Two-Day Snowfall Totals, 18-19 February 1984

Many snow events are associated with small-scale short waves that do have deformation cloud zones within the vorticity field such as shown in Figure 4-141 over eastern Kansas and Nebraska and Iowa. These systems move quicker across the CONUS than the slower-moving large-scale commas. Snowfall amounts are generally less than the big storms.

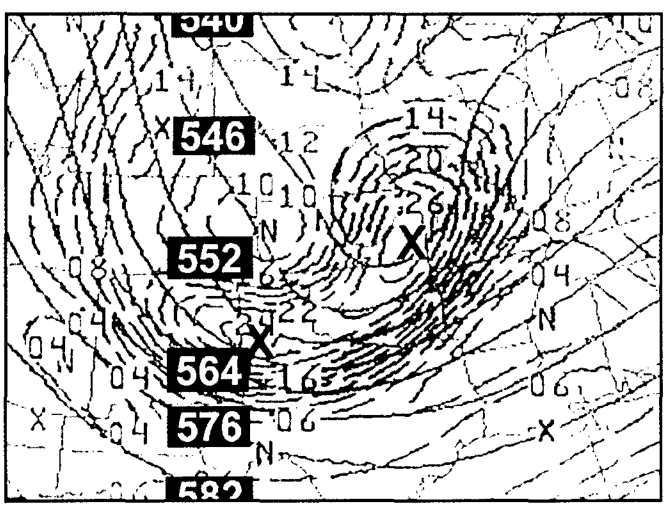

Figure 4-141. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/18 December 2000

Middle and high level dry slots occur with all mature comma systems such as shown in this March event (Figure 4-142). Visible images often show low clouds below the dry slot, however, there is none or very little precipitation (flurries). This is a forecasting problem anywhere across the CONUS. The question arises, "Will we be dry slotted?" The height fall center track generally lies along the western side of the dry slot. The IR photo, Figure 4-142 (another storm system, not related to the storm system shown earlier in Figure 139), a dry slot is shown over eastern Kansas and western Missouri. The white arrow represents the forecast height fall track. The thick **L** is the 500 mb low position. The thin **L** is the surface low position. The **X** is the estimated HFC position at 1200Z. As can be seen in the image, the extensive snow area within the deformation cloud system is to the left of the HFC track. Warm frontal rains are occurring within the warmer baroclinic cloud system over eastern Missouri and eastward.

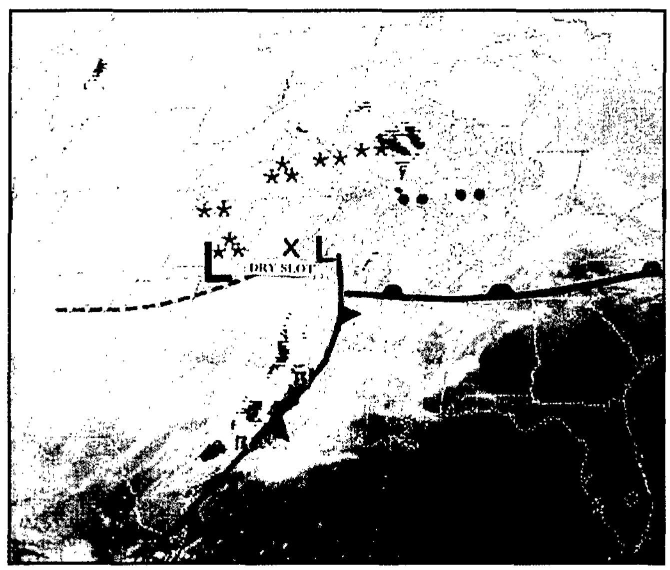

Figure 4-142. GOES-E IR, 1201Z/19 March 1984

Frontal positions from the 1200Z NWS surface analysis.

Determination between rain versus snow using height fall center and vorticity center tracks where warm air advection has occurred ahead of a developing storm (mostly receding high) were shown to be reliable in many case studies for the past 30+ years.

There are many empirical rules-of-thumb available to use to determine what type of precipitation is expected. These empirical rules are based mostly on thickness and temperature thresholds. An excellent rule east of the Rocky Mountains for a snow or no snow forecast is the 1000-500 mb 540 thickness isopleth.

Non-Convective Surface Wind Regimes (Notorious Wind Boxes)

Northern Great Plains Box

Southeastward moving storms such as shown earlier in the Alberta Low regime often trigger the Livingston Box and later activating the Northern Plains Box. Because surface wind gusts do not confine themselves to the basic Livingston box as the storm system tracks eastward, this becomes an important storm track. Figure 4-143 depicts a northern Great Plains Alberta Low storm track. A typical low-level maximum wind chart is shown in Figure 4-144.

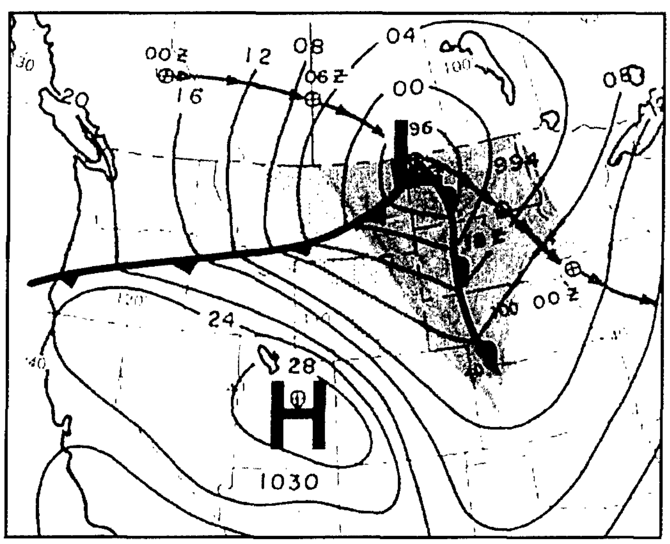

Figure 4-143. Livingston and Northern Plains Boxes Surface

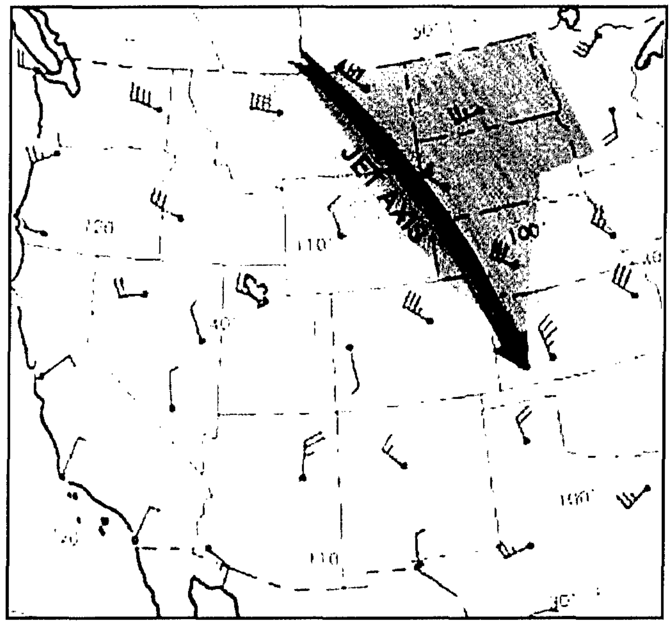

Figure 4-144. Livingston and Northern Plains Boxes Low-Level Maximum Winds

Another Northern Plains wind event that should be considered is shown in Figure 4-145. Rapid-moving secondary troughs following a cold frontal passage are capable of activating the Northern Plains Box. In Figure 4-145, tight isobaric packing and isobars with a northeast-southeast orientation are shown. Moderate to strong surface-pressure change rise centers and their continuity of movement are very important to forecast a wind outbreak (see inset in Figure 4-145). There is an empirical rule that uses the time the rise center crosses the Canadian borders to predict the onset of 35 knot gusts (after sunrise; from AWS-TR-219).

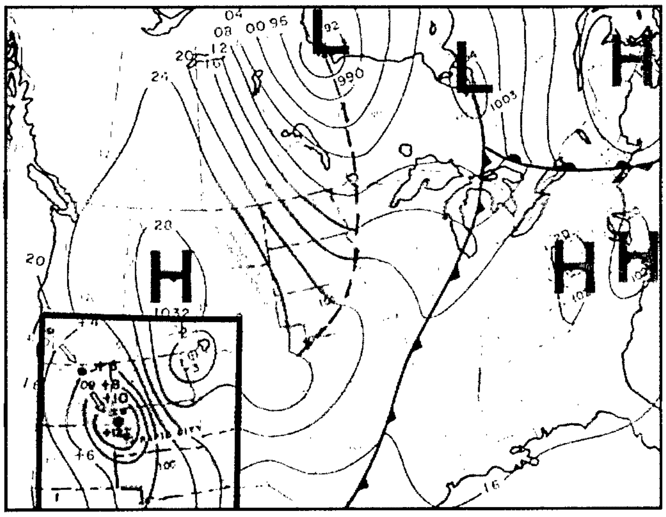

Figure 4-145. Northern Plains Box, Secondary Troughs Example
Inset: Pressure rise centers.

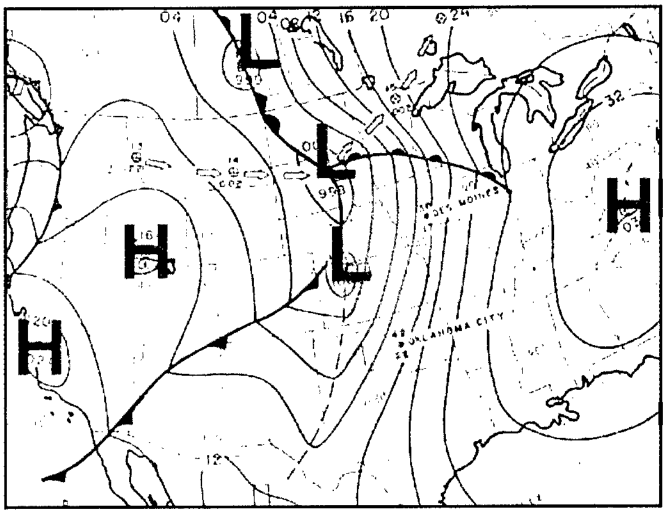

Figure 4-146. Central Plains Box

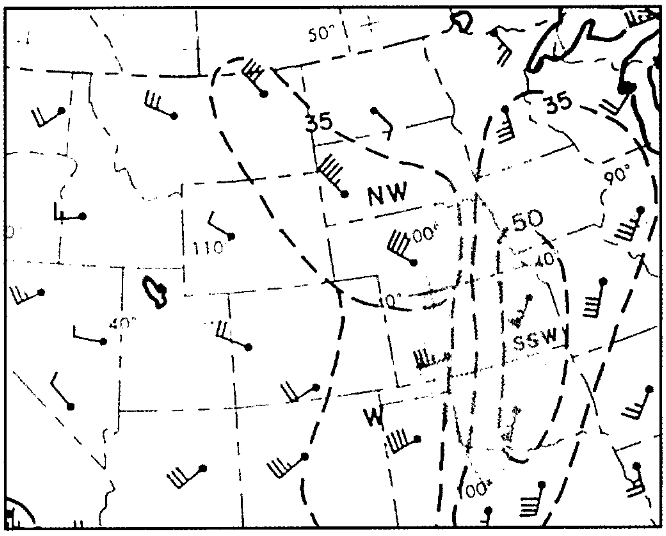

Figure 4-147. Central Plains Box Low-Level Maximum Winds

Central Great Plains Box

Although this wind event is more likely during the spring season, it will occur during the winter season when strong mP frontal systems move out of the Rocky Mountains. The surface pressure gradient tightens between the front and the receding polar ridge to the east. The southerly low-level jet becomes strong and is reflected on the surface by strong southerly winds (considerable discussion on this wind regime and the low-level jet was presented earlier in this section). Figures 4-146 and 4-147 illustrate a typical pattern. The initial and forecast boundary layer wind and 850 mb charts are tools for predicting the area of strong southerly winds. As shown in Figure 4-146, the lee-side trough is always on the western side of the strong wind event. The shaded area in the maximum wind chart, Figure 4-147, depicts the low-level jet. Surface winds >35 knots are more likely over the Central Plains during the heating hours; the winds often lessen to 25-30 knots during the evening hours prior to cold frontal passage.

In this example (Figures 4-148 and 4-149) a strong south to north pressure gradient developed as a result of the following scenario:

- An Atlantic low- pressure system off shore was quasi-stationary.
- The elongated polar ridge over the eastern CONUS was unable to move east (blocked).
- The mP cold front over the Rockies tightened the gradient on the west side of the polar ridge.

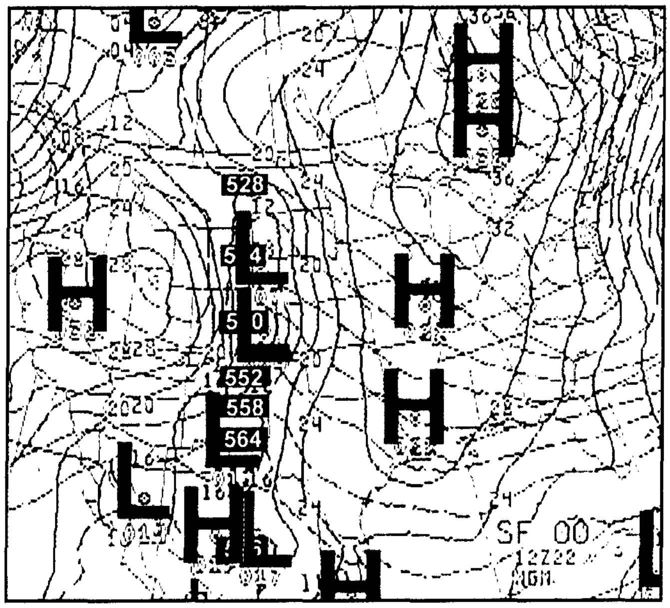

Figure 4-148. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/22 February 1999

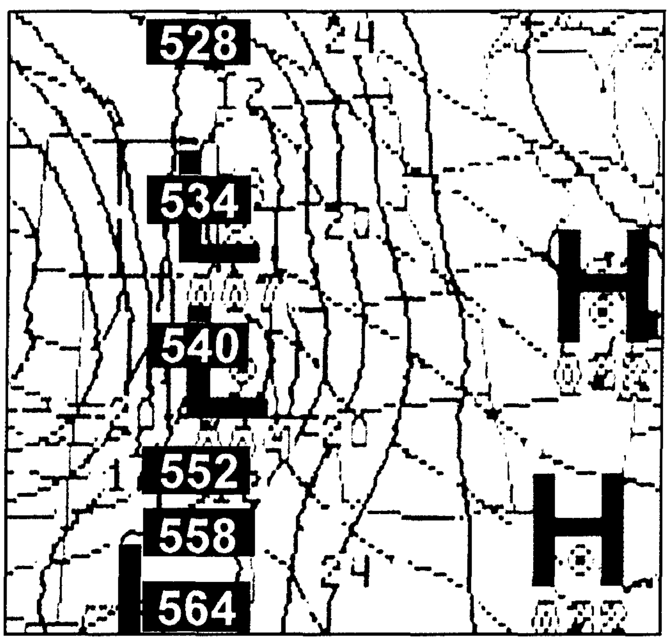

Figure 4-149. Same as Figure 4-148, Just Blown Up

Note the strong south-north gradient in the Plains.

Dusty Box

Although the Dusty box (Figures 4-150 and 4-151) normally appears in the spring of the year, it may occur during the winter from strong, low-latitude storm systems.

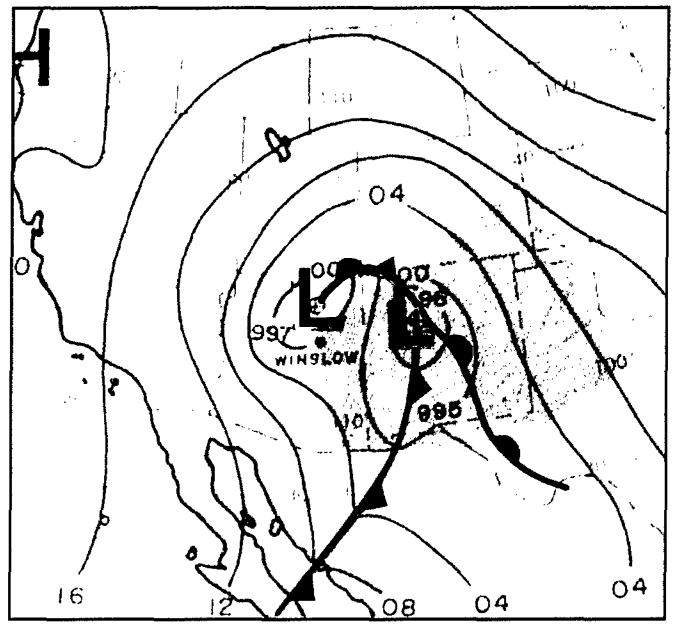

Figure 4-150. Dusty Box Surface

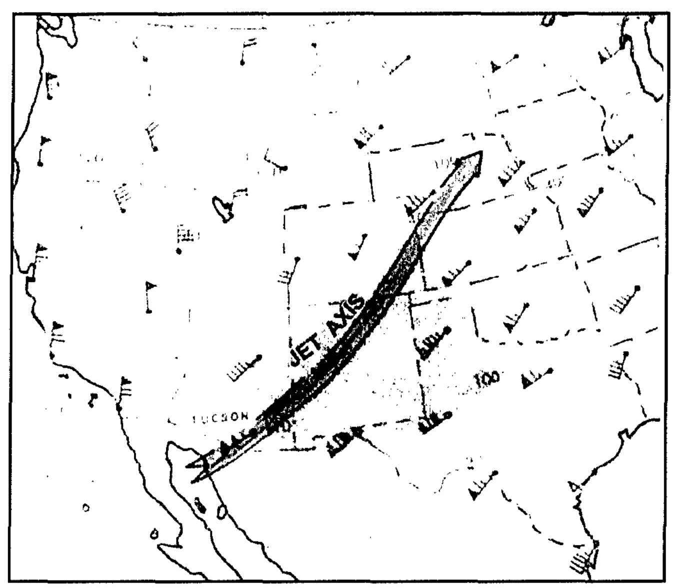

Figure 4-151. Dusty Box Mid-Level Maximum Winds

Although not included as a notorious wind regime, cold air advection winds that develop within the tightening pressure gradient of a deepening Great Plains storm system occur often during the winter season (Figure 4-152). First indicators of a strong wind outbreak (≥35 knots) are Colorado and Wyoming locations along and east of the Front Range. Doppler wind products and wind profilers over these areas will alert forecasters to the beginning of a strong wind outbreak. Occurrences of cold air wind outbreaks, associated with deepening lows can occur anywhere over the central CONUS.

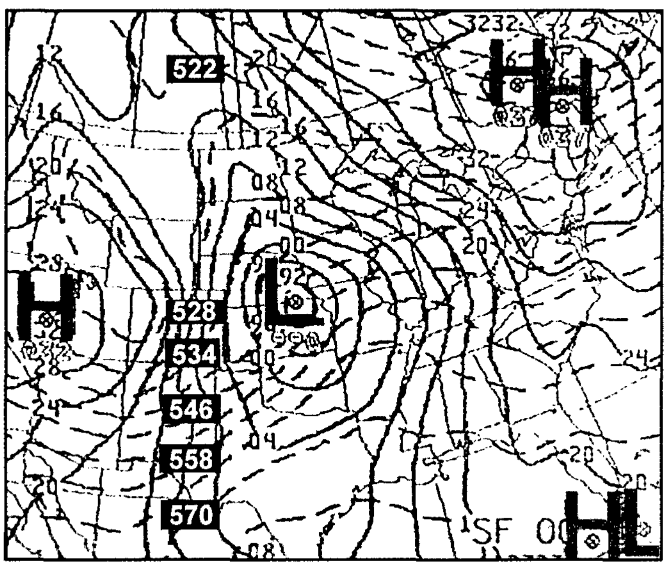

Figure 4-152. Surface, 1200Z/ 27 November 1994
Strong cold air winds have occurred over eastern Colorado and New Mexico and the western High Plains.

Winter Thunderstorm Regimes

A decrease in the frequency of thunderstorm occurrences would be expected during the generally cold, stable air masses that track across the CONUS. Forecasters should not become complacent when days or weeks will go by without any significant convective activity. Severe thunderstorms including tornadoes will occur over the southern states and may extend as far north as the central CONUS when moist and unstable Gulf air advects northward ahead of an approaching upper-level system. Let's look at several winter thunderstorm patterns.

Prevailing High – Polar Front Activity

Under a prevailing high-pressure regime, thunderstorms occur along the polar boundary that usually lies across the Gulf coastal states generally from central and southern Texas, and eastward to Florida. Frontal thunderstorms are likely further to the north when the polar boundary shifts northward ahead of a southern Rockies disturbance. Frontal waves, associated with short waves, will enhance convection when moist Gulf air advects northward. Severe thunderstorms and tornadoes (usually squall line activity) occur with these frontal waves as they move across the southern regions of the Gulf coastal states. Figures 4-153 and 4-154 illustrate two examples.

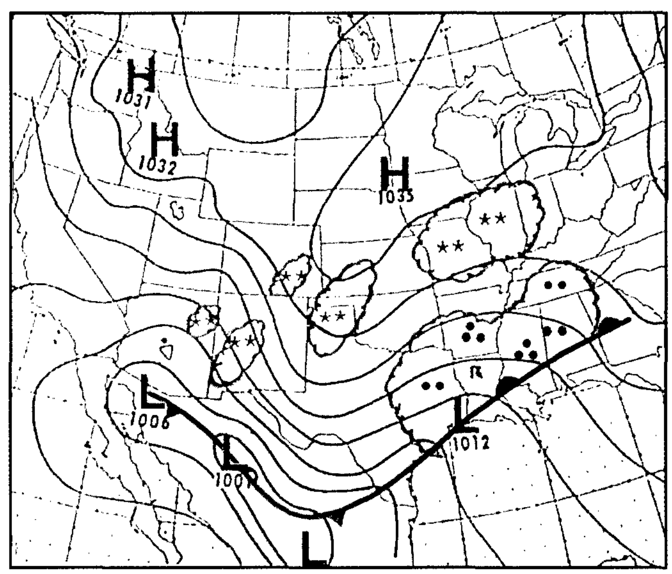

Figure 4-153. Surface, 2100Z/8 February 1980
Thunderstorms along and north of polar front.

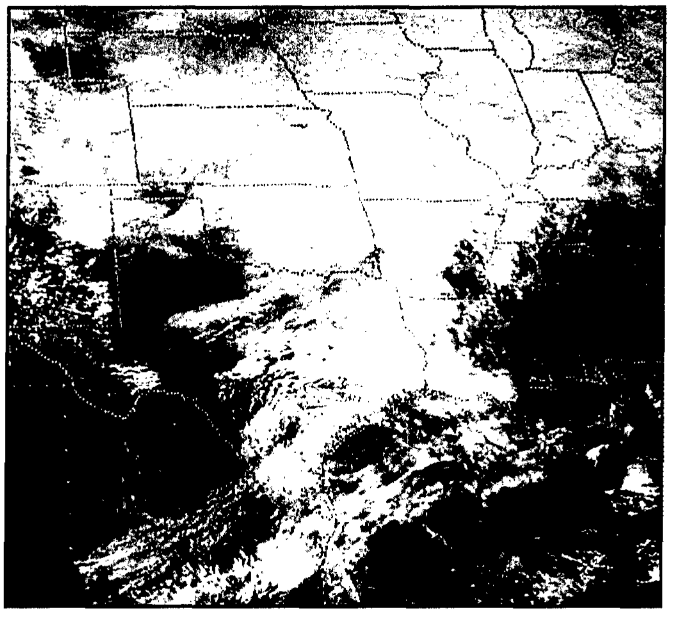

Figure 4-154. GOES-E VIS, Early February
Thunderstorms have developed over central Texas along and south of the polar front. Not related to Figure 4-153.

Prevailing High – Elevated Convection

Occasionally, thunderstorms will develop further to north from the east-west stationary polar front. These elevated thunderstorm events are difficult to forecast because, where they form, the surface air mass is stable within the polar ridge. The air mass above the shallow polar ridge may be unstable when southerly moist air occurs above the inversion. Surface-based lifted analysis charts do not help; one must look at lifted indices above the inversion level. When elevated convection does occur (often over northern Texas, Louisiana and Mississippi), these thunderstorms will align east to west and reflects the polar front alignment to the south.

Receding High

These thunderstorm events, when they occur, are often widespread and produce severe thunderstorm (and tornado) outbreaks and are associated with cold frontal systems of large-scale comma systems. Warm air and moisture advection associated with the low-level jet advects rapidly northward ahead of these cold fronts (this scenario was presented earlier in this chapter). Several examples are shown in Figures 4-155 through 4-158.
Note: Two examples of widespread severe thunderstorms and tornadoes will be shown in Chapter 5 (Eastern CONUS) under Lower Mississippi cyclogenesis.

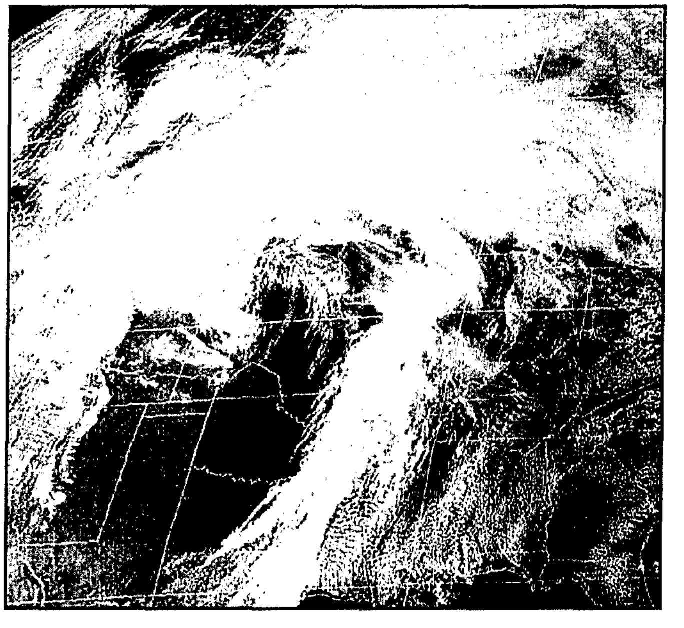

Figure 4-155. GOES-E VIS, 1932Z/ February 2000

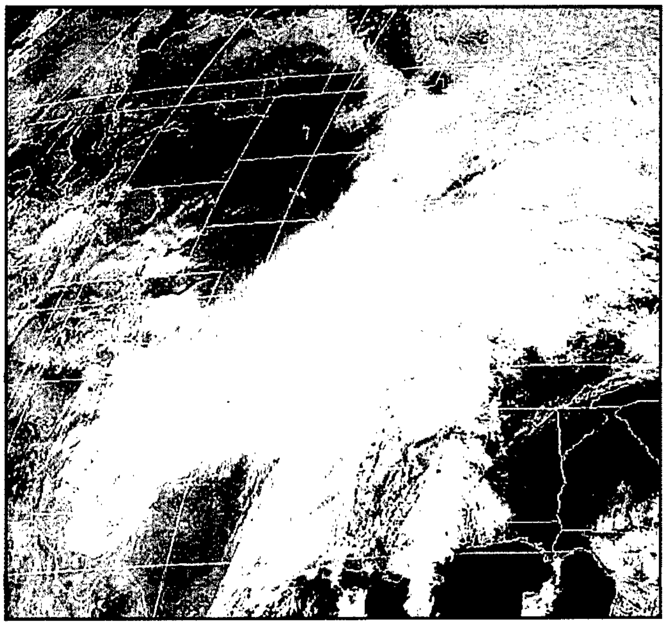

Figure 4-156. GOES-E VIS, 1846Z/ 4 December 1999

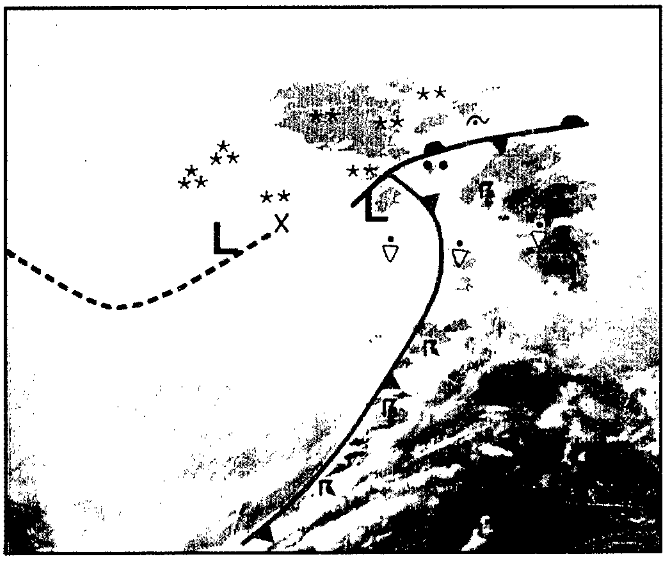

Figure 4-157. GOES-E Enhanced IR, 0030Z/ 27 November 1983
Frontal thunderstorm developed with a moist, unstable air mass.

Figure 4-158. GOES-E Enhanced IR, 0100Z/ 31 January 1982
The vorticity comma cloud within this comma is easily identifiable by the black shades.

It is not uncommon for non-severe thunderstorm to occur within the deformation zone snow areas of large winter storms such as shown in Figures 4-155 through 4-158. These quasi-stationary convective bands produce heavy snowfall sometime as much as four times the amount reported in the surrounding areas. To the observer, it would be difficult to hear thunder due to the accompanying strong surface winds and sound absorbed by the snowflakes. Lightning flashes can be observed, but they have a weak glow through the snowflakes.

Freezing Precipitation

Synoptic-scale freezing precipitation events generally begin by late-November over the central and northern CONUS, as continental polar (cP) air masses become the dominant anticyclonic systems. The following information was extracted from AFWA /TN-98/001, *Freezing Precipitation.* The information that follows would include the central and eastern CONUS.

Three different regimes of precipitation events were noticed based on the study of empirical evidence. "Frontal overrunning" is the most common regime, and represents warm air moving and lifting over a cold air mass, until the warm air cools to condensation and precipitation occurs. "Undercutting" refers to those situations where a cold air wedge is moving underneath an existing warm air mass. "Cold air stratus" refers to those situations where warm air is advecting over a shallow cold air mass, but the precipitation (generally freezing drizzle) is observed from stratus within the cold air.

Warm Air Advection

Warmer air lifting over a shallow continental polar front (usually warm or stationary frontal overrunning) or low-level warm air advecting northward with a southerly flow of a retreating polar high (no warm front exists; usually a freezing drizzle event) account for many freezing precipitation events.

Increasing ridge development indicates continued warm air advection. Of course, considerations for moisture and lift should be determined to forecast the onset of freezing precipitation. Ridge configurations come in all sizes. In warm air advection events, the most telltale feature for development of freezing precipitation is a thickness and temperature ridge (Figures 4-159 and 4-160). Freezing precipitation often occurs at the apex of thickness and temperature ridges (Figures 4-159 and 4-160) and near (usually north of) an 850 mb low (not shown).

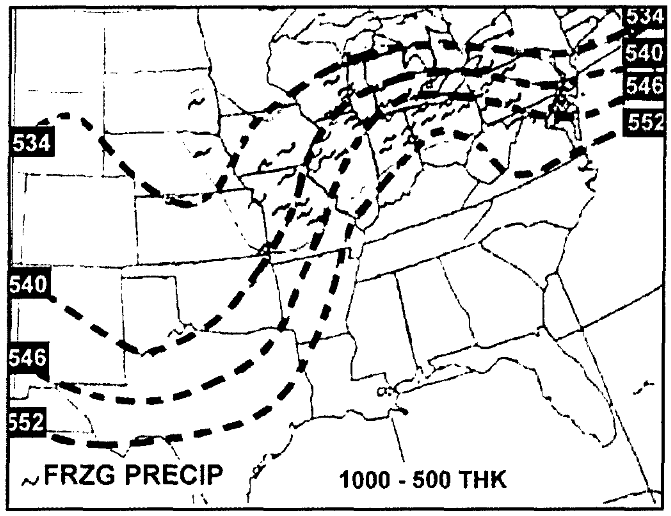

Figure 4-159. Thickness Ridge and 6-Hour Observed Freezing Precipitation, 1200Z/ 11 January 1991

Freezing precipitation is often observed at the apex of the thickness ridge.

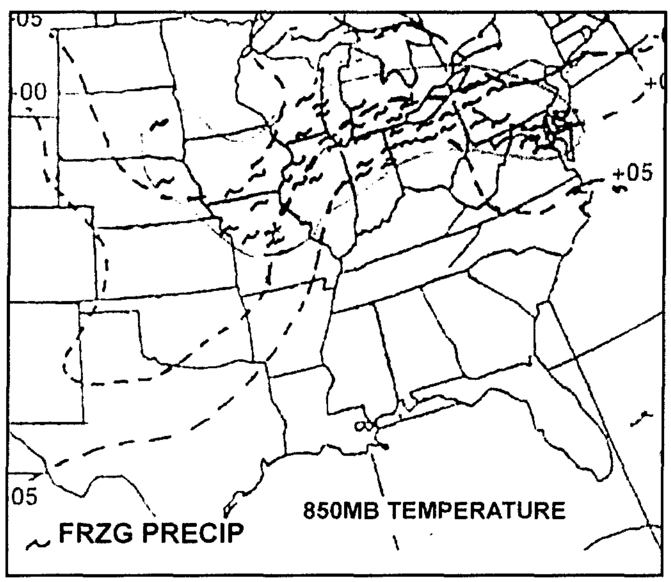

Figure 4-160. Temperature Ridge and 6-Hour Observed Freezing Precipitation, 1200Z/ 11 January 1991

Freezing precipitation is often observed at the apex of the temperature ridge.

Figures 4-161 through 4-164 depict examples of temperature and thickness ridges associated with warm air advection and their relationship with freezing precipitation. In Figures 4-163 and 4-164 (related to Figures 4-161 and 4-162), arrows mark the freezing precipitation area within the thickness and temperature axes on the surface (1,000-500 mb thickness) and the 850 mb analysis.

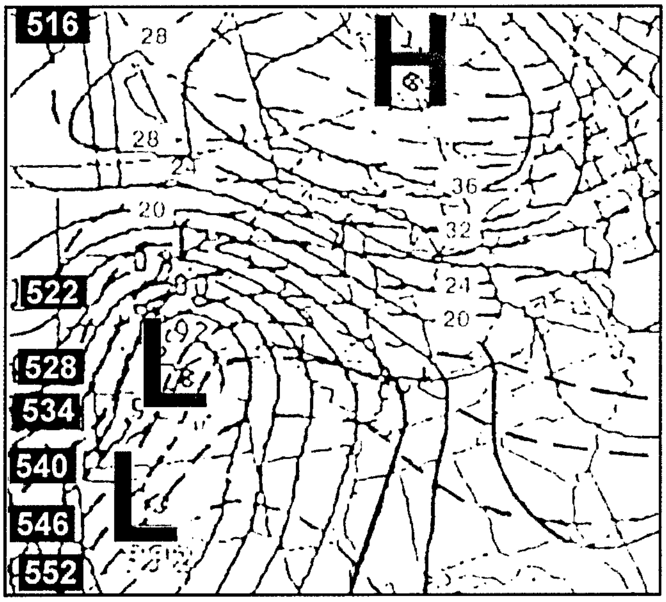

Figure 4-161. 00HR MSL PRES/1000-500 THKNS, 0000Z/4 March 1985

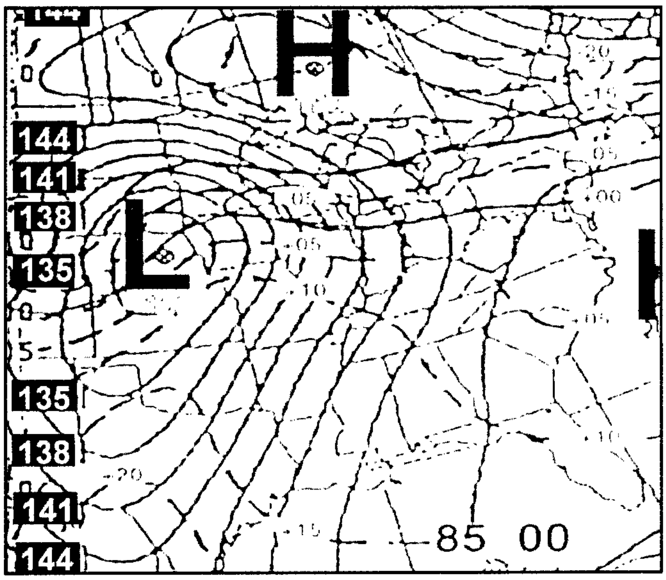

Figure 4-162. 00HR 850 mb HEIGHTS/TEMPS, 0000Z/4 March 1985

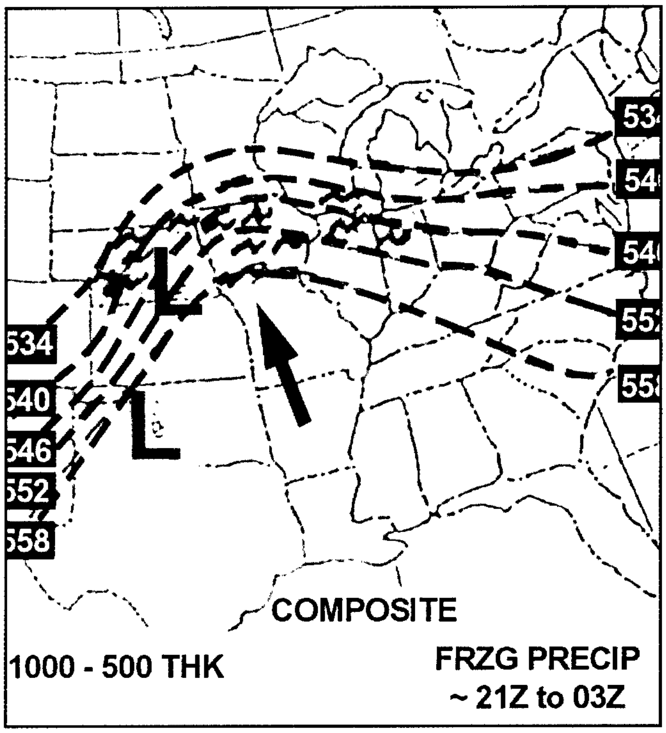

Figure 4-163. Thickness Ridge and 6-Hour Observed Freezing Precipitation, 0000Z/ 4 March 1985

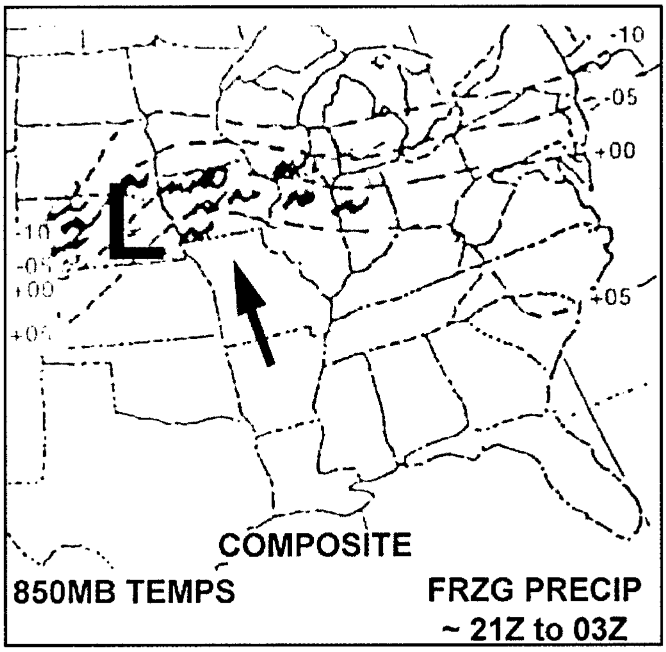

Figure 4-164. 850 mb Temperatures and 6-Hour Observed Freezing Precipitation, 0000Z/ 4 March 1985

Another example of significant freezing precipitation associated with warm air advection is shown in Figures 4-165 through 4-167. At the surface in Figure 4-165, a warm front appears to be developing across the Southern Plains to the Lower Mississippi River Valley (see arrows). The freezing precipitation area is along and north of the developing warm front. In Figure 4-166, freezing drizzle extends northward into the 528 thickness apparently due to strong low-level warm air advection. In Figure 4-167, freezing rain is shown from Nebraska/Kansas and eastward to Ohio and Kentucky. Freezing drizzle is noted north of the freezing rain belt from Minnesota southeastward to northern Ohio. Freezing drizzle occurrences into the 850 mb -10° to -15° C temperature ribbon and the 534-522 thickness ribbon may occur within strong warm air advection events.

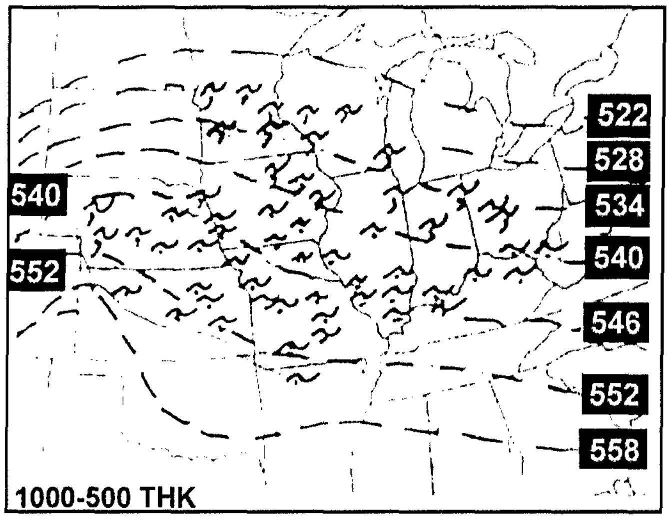

Figure 4-166. Thickness and 6-Hour Observed Freezing Precipitation, 0000Z/15 February 1995

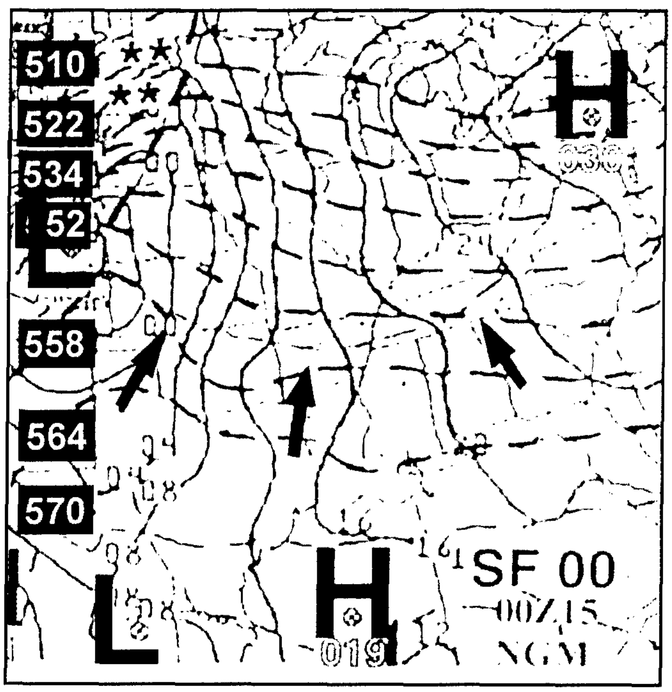

Figure 4-165. 00HR MSL PRES/1000-500 THKNS, 0000Z/15 February 1995

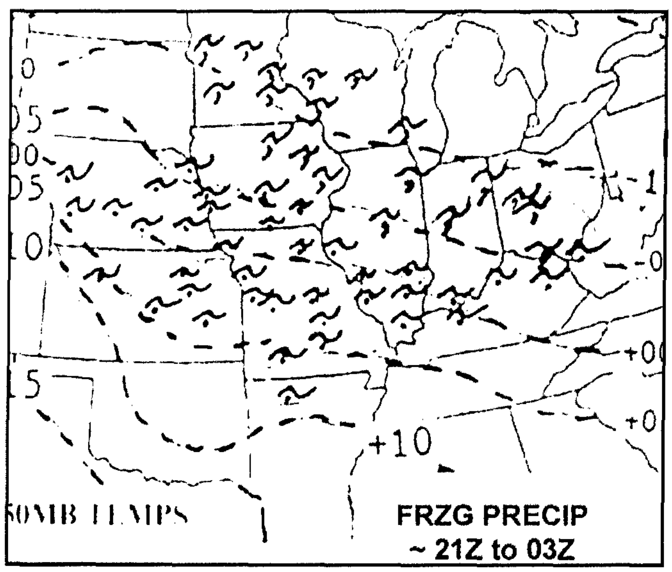

Figure 4-167. 850 mb Temperatures and 6-Hour Observed Freezing Precipitation, 0000Z/ 15 February 1995

Figure 4-168 depicts a typical storm system over the central CONUS when the polar high retreats eastward. Warm frontal freezing rain will lie between the 540 and 552 thickness isopleths when the 552 thickness isopleth is north of the warm front. Occasionally, the 552 thickness isopleth will be located south of the warm front; in these cases, either use the 546 thickness isopleth or the warm front as the southern boundary of freezing rain. A narrow band of freezing precipitation may occur after cold FROPA as shown in Kansas and Oklahoma in Figure 4-168.

Neutral Advection

Figures 4-169 and 4-170 show a neutral advection pattern; it is called neutral advection because no noticeable cold or warm advection occurs at the surface. Above the shallow cold dome, however, southerly winds bring warm, moist air northward over the frontal boundary to increase cloudiness and precipitation. The freezing precipitation width is narrow from south to north (less than 200 nm) but quite extensive from west to east and can extend in excess of 500 nm as shown in Figures 4-169 and 4-170.

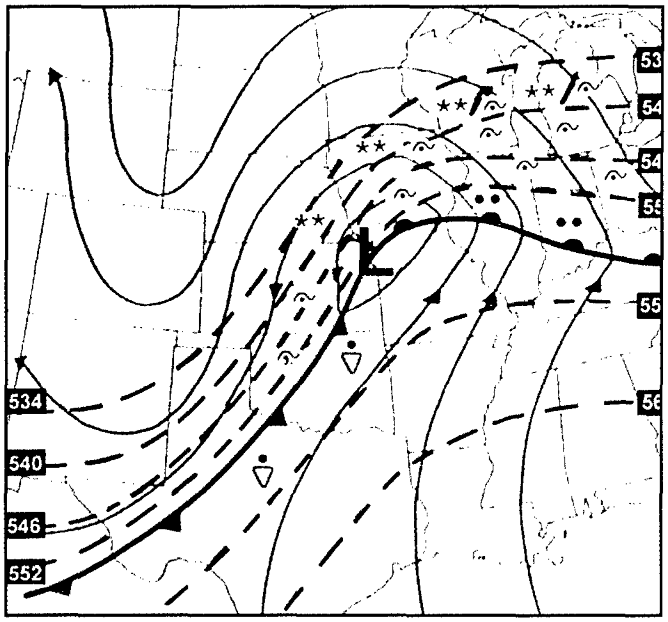

Figure 4-168. Warm Air Advection Situation
The figure shows warm air advection freezing rain pattern with freezing rain occurring between the 552 and 540 thickness isopleth.

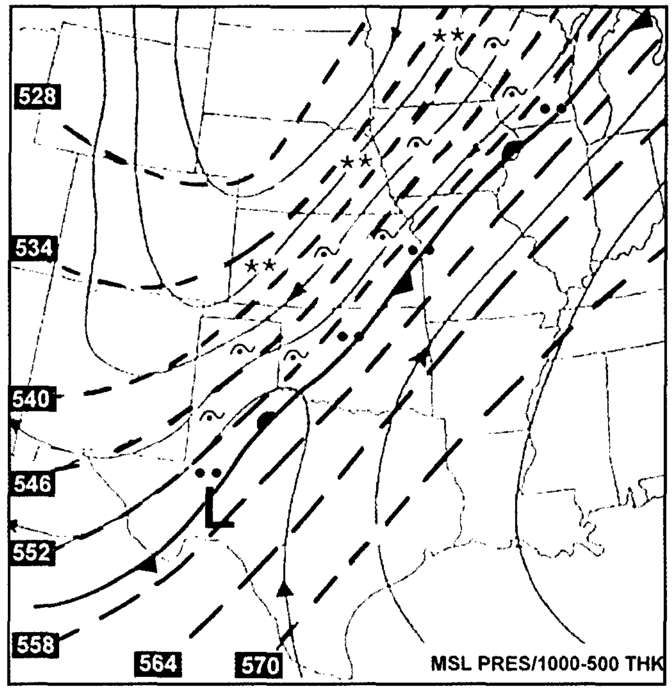

Figure 4-169. Central and Northern CONUS Neutral Advection Situation
The surface isobars behind the polar front are aligned from northeast to southwest, and the thickness flow is from southwest to northeast. Freezing precipitation occurs between the 552 and 540 thickness isopleths and between the +5° C to -5° C 850 mb isotherms.

The information just presented dealt with warm air advection thermal and thickness ridges that occur often. However, there are situations where no thermal or thickness ridges exist and, yet, a freezing precipitation event occurs. These events are named neutral advection and will be presented in Figures 4-169 and 4-170.

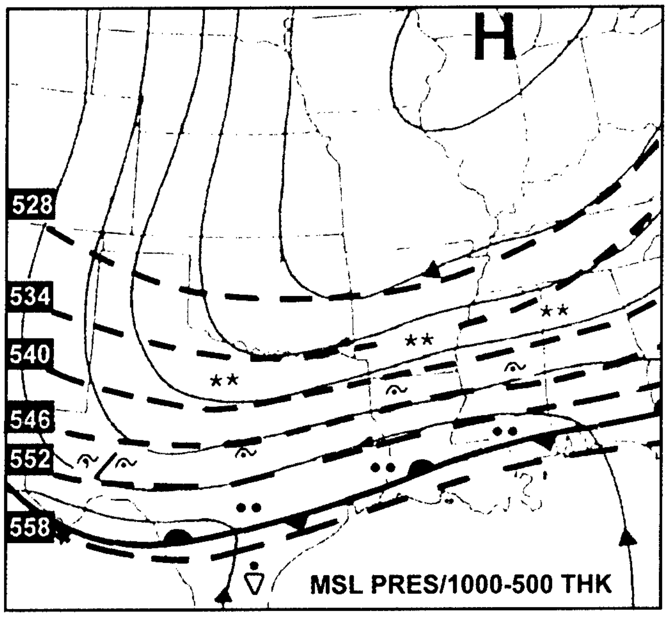

Figure 4-170. Southern CONUS Neutral Advection Situation
The surface isobars behind the polar front are aligned east to west (easterly flow), and the thickness flow is from west to east. Freezing precipitation occurs between the 552 and 540 thickness isopleths and between the +5° C to -5° C 850 mb isotherms.

Cold Air Advection – Undercutting

Unlike overrunning, where warm air lifts over cP air, undercutting occurs when shallow cP air moves into an existing rain or drizzle area. The temperature drops below freezing resulting in freezing precipitation. In the northern CONUS, undercutting is a short-lived event as cold air advances eastward; however, it may last longer across the southern CONUS where the cold dome is shallow.

Undercutting occurs most often across the central and southern Great Plains to the Gulf Coast. Often, precipitation develops with the return of Gulf moisture and/or precipitation that has moved out of the Rockies sometime before the arrival of a cP cold front. In many undercutting cases, freezing precipitation occurs between the 1,000 to 500 mb thickness 558-540 isopleth ribbon and the 850 mb temperature +10° C to 0° C ribbon.

In Figure 4-171, note the prefrontal precipitation is occurring within the 552 to 558 thickness isopleth ribbon over the Central Plains (noted by the arrows). A surge of cP air is moving southward. A narrow band of undercutting freezing rain is shown across the Texas Panhandle and into central Kansas.

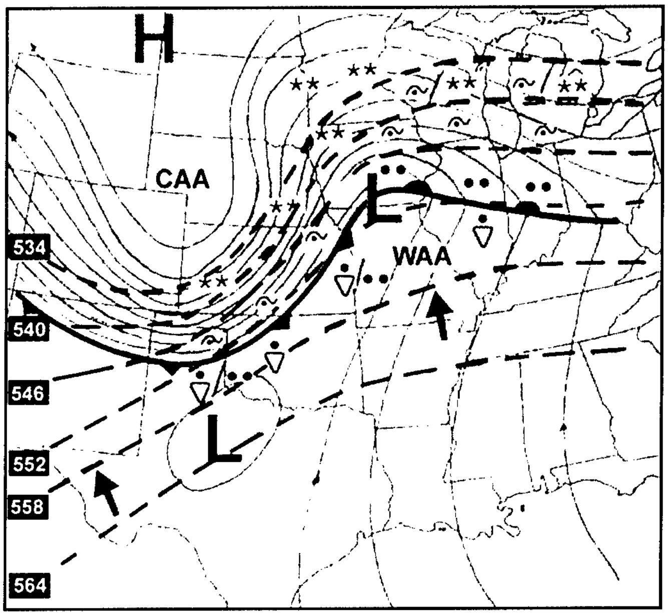

Figure 4-171. Undercutting Freezing Precipitation
Prefrontal rain falls within the 552 to 558 thickness isopleths. Freezing rain occurs behind the cold front.

Twelve hours later in Figure 4-172, the shallow cold air has advanced southward into central Texas and northward into Missouri. The freezing rain area has expanded as cold air moved into the previous prefrontal precipitation area shown in Figure 4-171. Since the cold air is shallow, the thickness column has not decreased sufficiently to change rain to snow. In Figure 4-172, notice that the 558 thickness isopleth is now north of the cold front as indicated by the arrows.

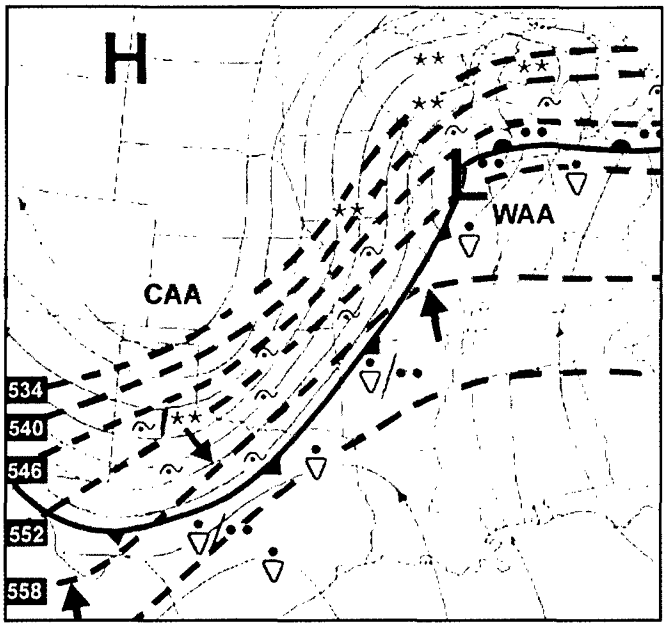

Figure 4-172. Undercutting Freezing Precipitation, 12 Hours Later

The 558 thickness isopleth is now located north of the cold front in the Texas and Oklahoma area (see arrow). Freezing precipitation expands northeastward.

Over the upper Great Plains, undercutting occurs within a narrower band after cold frontal passage. Generally, the cold front is oriented northeast- southwest which indicates the strongest cold air advection. On the other hand, undercutting occurs often over a larger area of the Southern Plains to the Gulf Coast as the cold front aligns east to west, an indication of weaker cold air advection.

Northern Great Plains – Warm Fronts

Alberta Lows tracking eastward within zonal flow across southern Canada often have a warm front extending southward into the northern Great Plains such as shown in Figure 4-173. The moisture source associated with these warm fronts is Pacific moisture within a fast moving westerly flow. Moisture that manages to survive the drying effects of mountains moves into the Northern Plains and overruns shallow cP air as shown in Figure 4-173. In these events, warm frontal freezing rain is often patchy in areal coverage, is of light intensity, and generally falls from mid-level cloud layers.

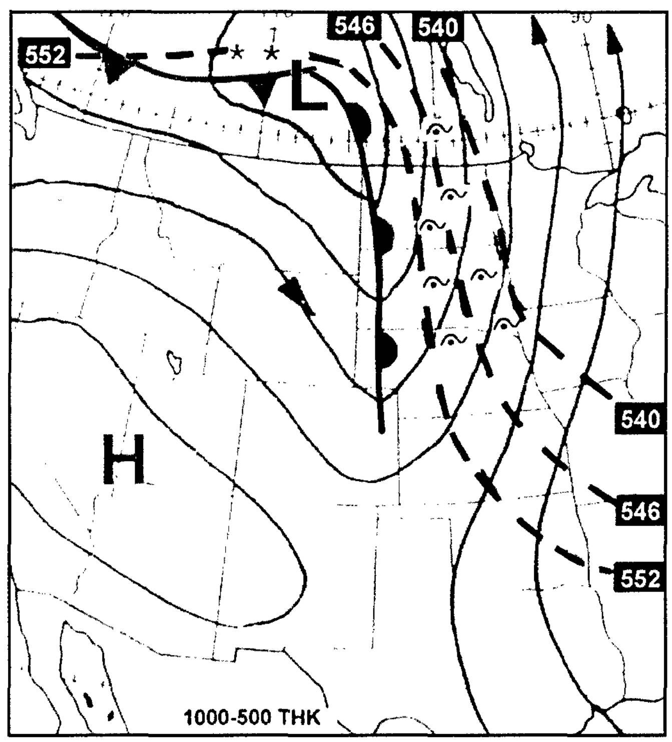

Figure 4-173. Northern Great Plains Warm Fronts

The figure shows a warm front extending southward from a zonal Alberta Low.

Northern Great Plains – Stationary Fronts

Continental polar air masses occasionally remain stationary over western and central Canada but continue to build. The upper flow is generally from the southwest. The southern boundary of the cP air mass is often observed from eastern Montana extending eastward across the Northern Plains as shown in Figure 4-174. Within the cold air behind the front, an extensive area of low stratus and fog (easterly low-level flow) often forms. Freezing drizzle occurs frequently in this stationary event, especially in the upslope flow over the western Dakotas and eastern Montana region. Sometimes an east-west trough is depicted on the surface chart rather than a stationary front. This pattern will end when a low moves out of the Rockies into the Central Plains, and the cold air and ridging moves rapidly southward behind the low.

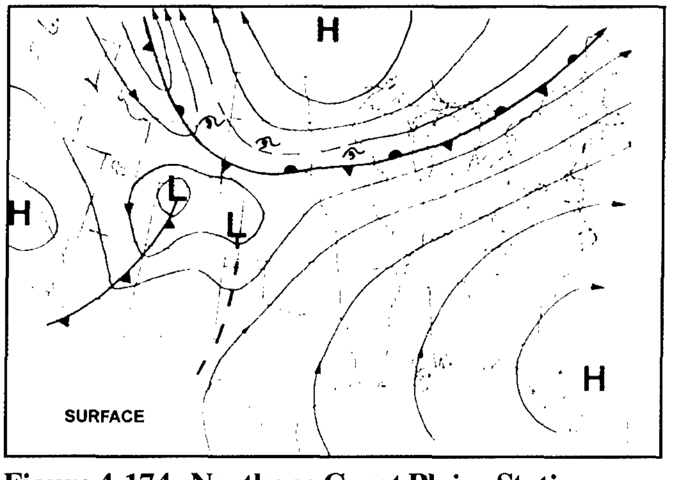

Figure 4-174. Northern Great Plains Stationary Front
Low stratus/fog and freezing drizzle occur within the cold air behind the polar front.

As a result of these stagnant events (prevailing high, neutral advection) and warm fronts moving northeast (receding high, warm air advection), the area stretching from Kansas and Oklahoma northeastward across Missouri to Ohio, and then, eastward across Pennsylvania and New York to the Atlantic Coast has a higher frequency of freezing precipitation. Figure 4-175 outlines this belt of freezing precipitation.

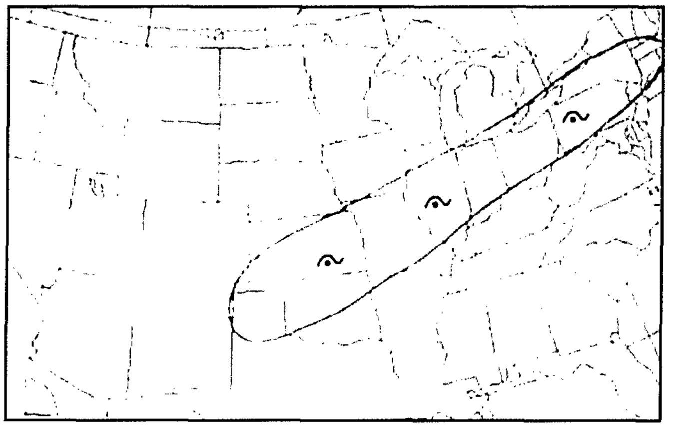

Figure 4-175. Model Freezing Precipitation Band
The precipitation results mostly from warm fronts moving northeast.

Many onsets of freezing precipitation, especially rain, begin over the western Great Plains with the return of Gulf moisture and moisture advection accompanying the approaching short wave. A favorite area for freezing precipitation development within a prevailing high-pressure pattern is over the Texas Panhandle and western Oklahoma area as depicted in Figures 4-176. Freezing precipitation outbreaks within a receding high pressure pattern usually develop further to the north over western Kansas and Nebraska.

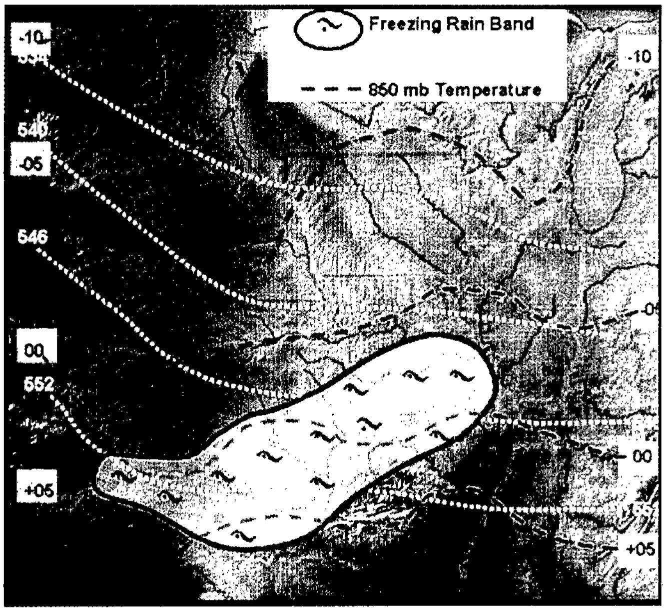

Figure 4-176. 1000-500 mb Thickness and 850 mb Temperatures Composite, 0000Z/ 5 January 1999

The figure shows a favored area for freezing precipitation development.

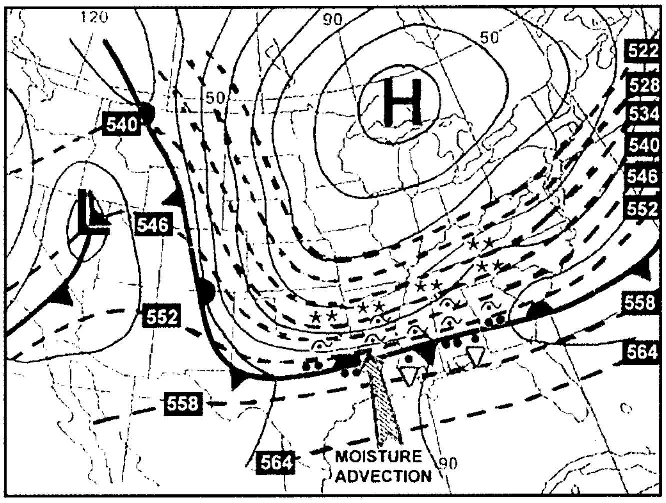

Figure 4-177. Typical Overrunning Situation

A fetch of Gulf moisture and low-level jet intersect the stationary boundary and establishes an overrunning event.

Another region favorable for freezing rain outbreaks is across the Lower Mississippi Valley when inverted troughs develop northward of a Gulf of Mexico frontal low (go back to Figures 4-113 and 4-114). Two prevailing high examples for overrunning events are shown in Figure 4-177 (model) and an actual occurrence (Figure 4-178). A fetch of Gulf moisture and the low-level jet intersect the stationary boundary and establish an overrunning event. In Figure 4-178, notice the extensive freezing precipitation and snow area from Nebraska to the East Coast.

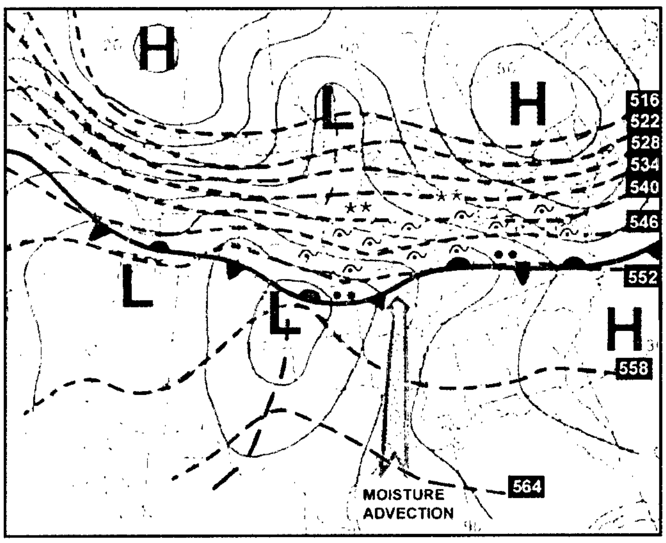

Figure 4-178. 00HR MSL PRES/1000-500 mb THKNS, 0000Z/27 February 1995

Extensive freezing precipitation extends from Nebraska to the East Coast.

Eastern CONUS

Cyclogenesis Regimes

Zonal and meridional upper air regimes have been presented in the previous two chapters. Many short wave low pressure systems that originate over the Midwest and in the western Gulf of Mexico become major storm systems over the eastern CONUS. The long wave trough frequently appears east of the Mississippi River during January and February. Many disturbances that affect the eastern CONUS are the result of short wave movements through the long wave. With the major ridge established over the western CONUS, weakening short waves travel across the ridge over Alaska and the northern Yukon then drop southward and intensify towards the upper Midwest and Great Lakes. Cyclogenesis appears on the surface usually along existing fronts in the path of these short waves. Storm deepening is rapid, especially when the short wave enters the long wave trough and begins to recurve northeastward.

Figures 5-1 and 5-2 depict two typical jet stream examples when the long wave is located over the eastern CONUS. Low-pressure systems originating over the northern Great Plains or from Canada drop southward and intensify within the long wave over the northeastern CONUS. Conversely, quasi-stationary long wave troughs east of the Mississippi River can produce intense storms over the eastern CONUS when two short wave impulses (from the northwest and southwest) interact within the long wave.

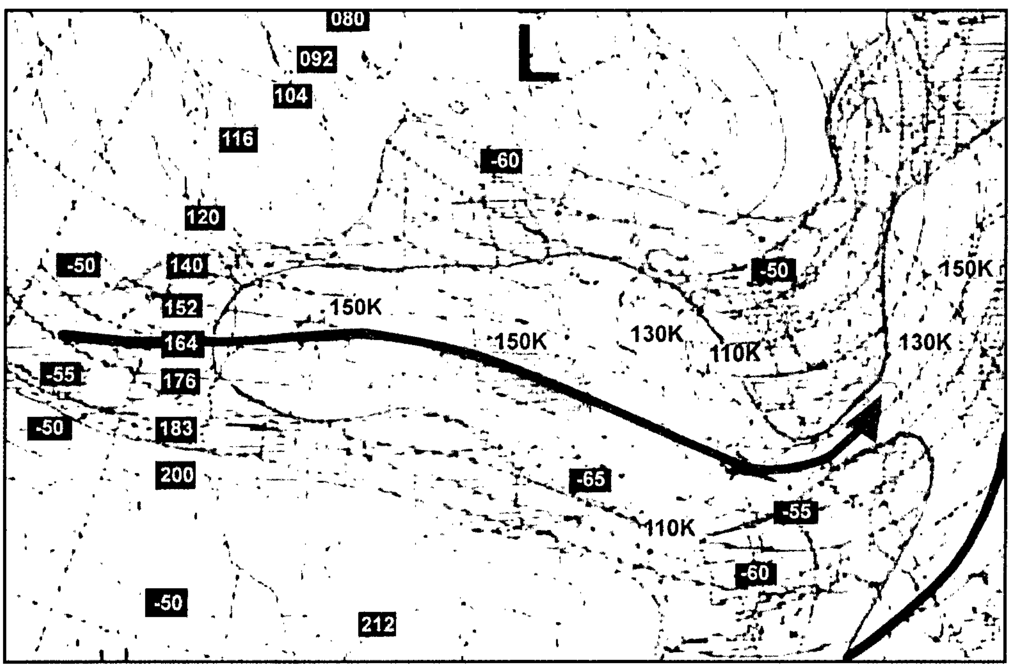

Figure 5-1. 300 mb, 1200Z/17 January 1982

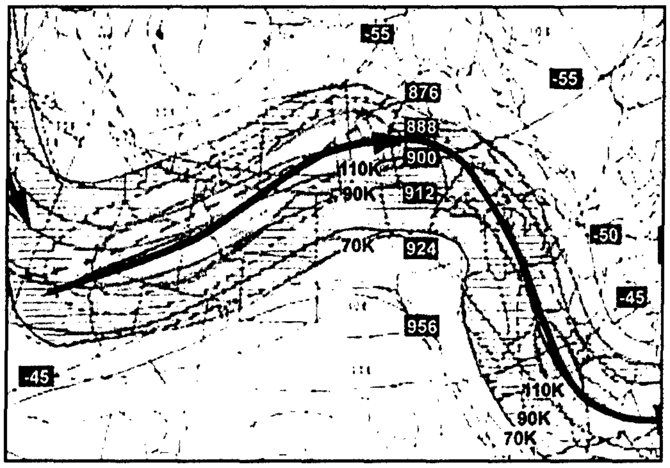

Figure 5-2. 300 mb, 1200Z/22 February 1982

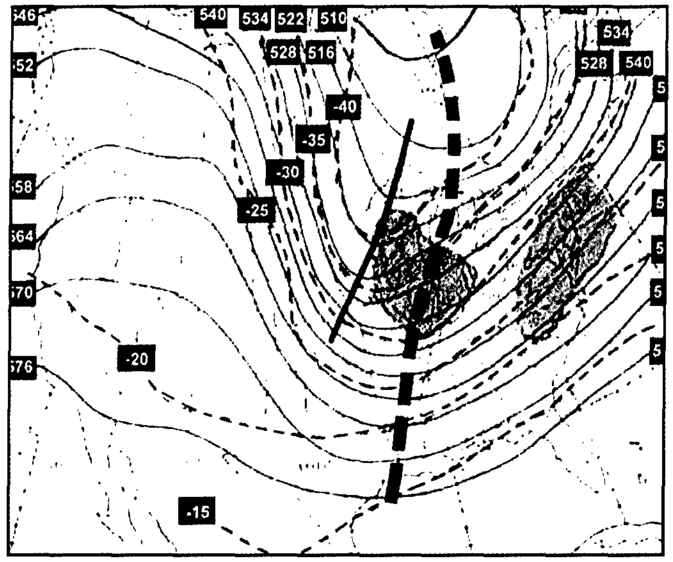

Figure 5-3. 500 mb, 1200Z/25 February 1979
Short wave moving into the long wave.

Figures 5-3 through 5-6 illustrate a case. In Figure 5-3, a short wave impulse appears over Lake Superior southeastward to the Central Plains (indicated by the thin black line). It is moving into the long wave trough as indicated by the wide dashed line in Figure 5-3. The surface chart (Figure 5-4; nine hours earlier then Figures 5-3 and 5-5) shows a frontal wave (Alberta Low, Meridional) over Iowa that developed as the short wave approaches. The surface chart (Figure 5-5) that relates to the 500 mb chart (Figure 5-3) shows that the low has moved into Illinois and had deepened six millibars. Later in the afternoon (Figure 5-6), the low had continued to deepen and heavy snow and gusty surface winds are affecting the Great Lakes and Ohio Valley region.

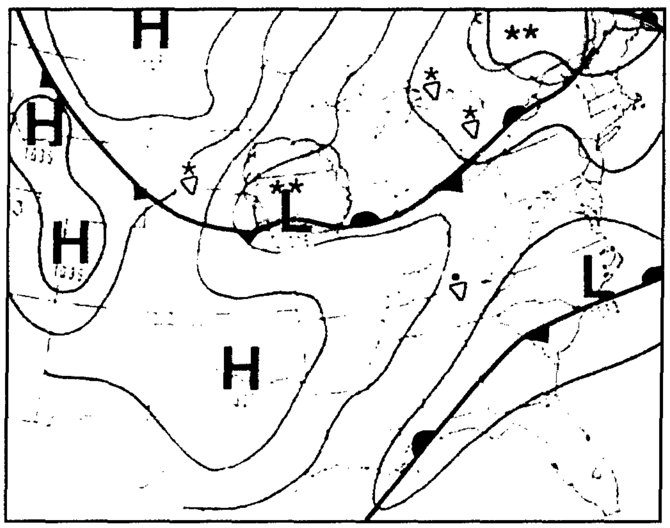

Figure 5-4. Surface, 0300Z/25 February 1979

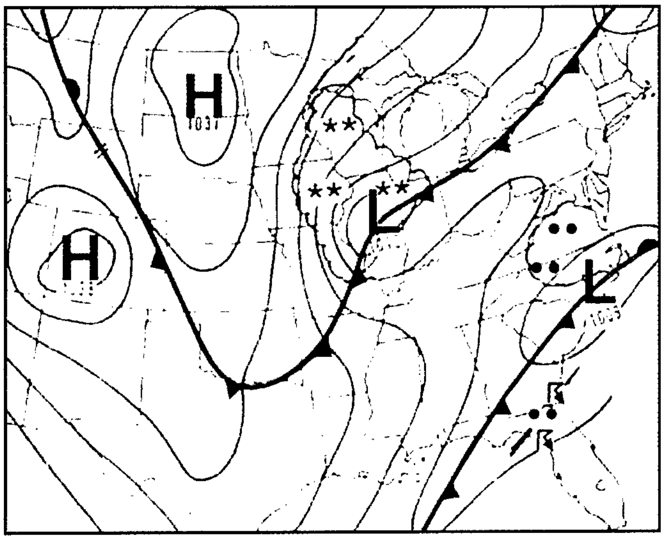

Figure 5-5. Surface, 1200Z/25 February 1979

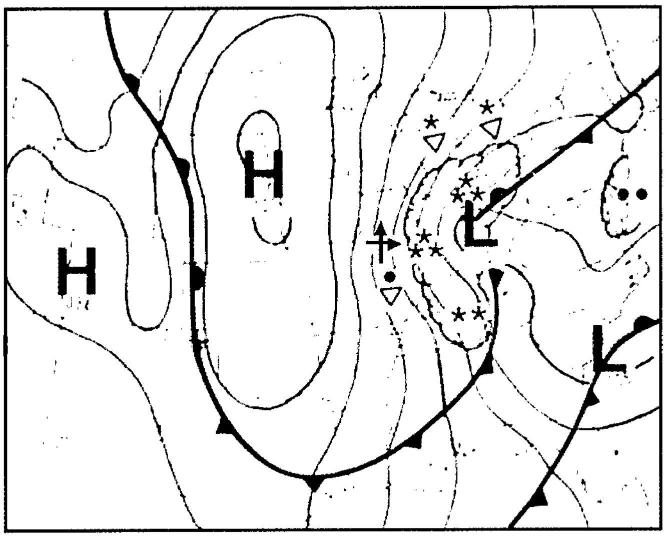

Figure 5-6. Surface, 2100Z/25 February 1979
Snow areas have increased.

Satellite charts (Figures 5- 7 and 5-8; 24 hours apart) show the developing short wave as it moves toward the Ohio Valley (see arrows).

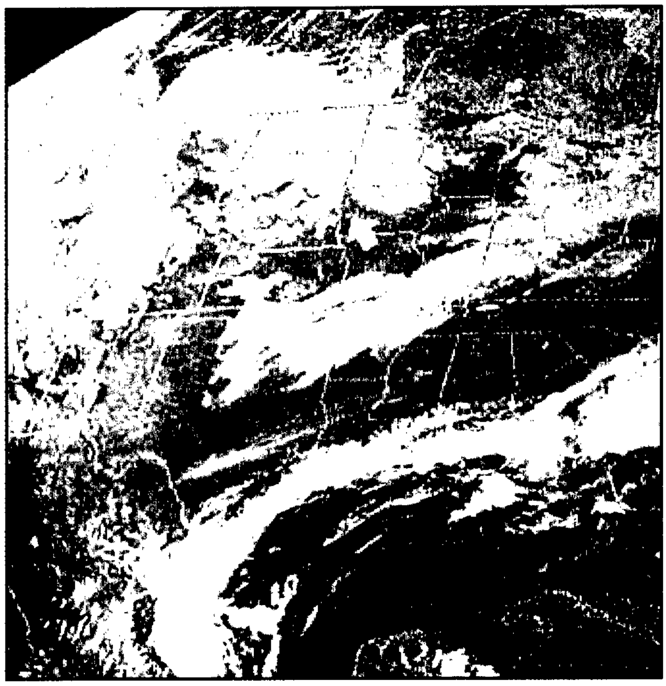

Figure 5-7. GOES-E VIS, 2116Z/ 24 February 1979

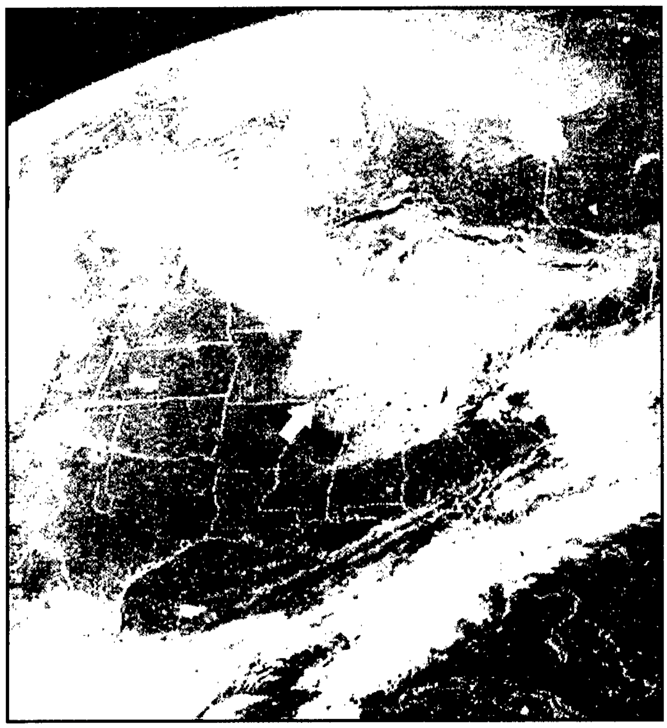

Figure 5-8. GOES-E VIS, 2116Z/ 25 February 1979

Another example of a Canadian short wave system that moved rapidly southeastward and deepened within the long wave is shown in Figures 5-9 and 5-10. Deepening short waves, travelling southward into the long wave, apparently shift the long wave westward by a few degrees. In Figure 5-9, the long wave retrogressed towards the Great Lakes-Ohio Valley. A 500 mb low has developed within the trough. At the surface (Figure 5-10), snow has increased over the Great Lakes and parts of the northeast CONUS as the Alberta Low (Meridional) deepened and moved southeastward.

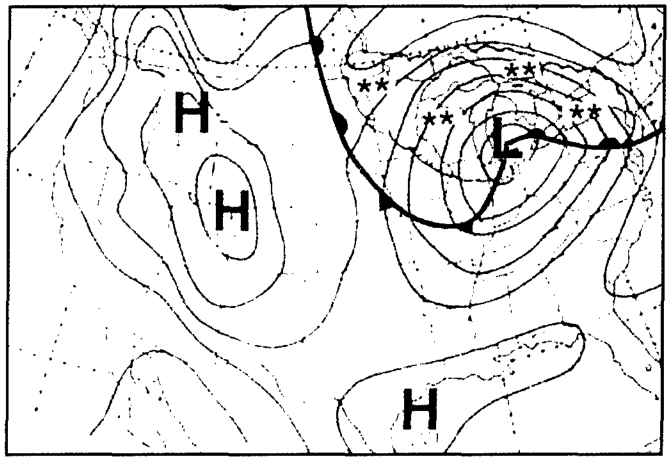

Figure 5-10. Surface, 1200Z/20 December 1975

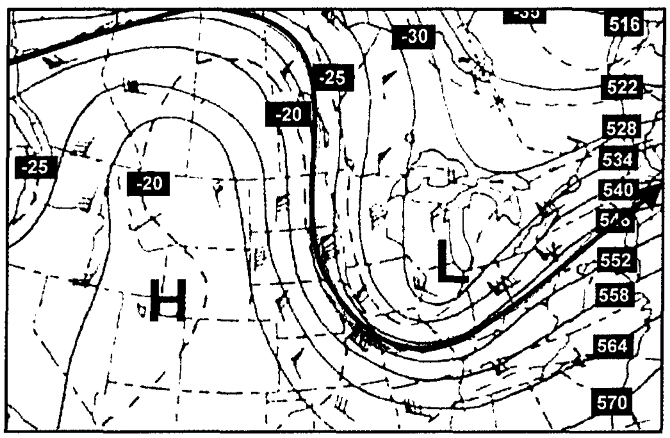

Figure 5-9. 500 mb, 1200Z/20 December 1975
Long wave located over the east-central CONUS.

The following sequence of analysis charts and visible satellite images shows a short wave comma cloud approaching and moving under a stationary baroclinic zone (long wave) located across the eastern CONUS. This event is identified as induced wave development on the large-scale baroclinic zone cloud system.

The 500 mb and surface analyses are respectively shown in Figures 5-11 and 5-12. In Figure 5-11, a long wave trough system is shown; the short wave responsible for comma cloud development, which will be shown in subsequent satellite photos, is difficult to locate within the long wave flow. At the surface, Figure 5-12, frontal waving over Pennsylvania has begun. The east-west kink in the isobars over the Great Lakes area is likely the surface reflection of the approaching short wave.

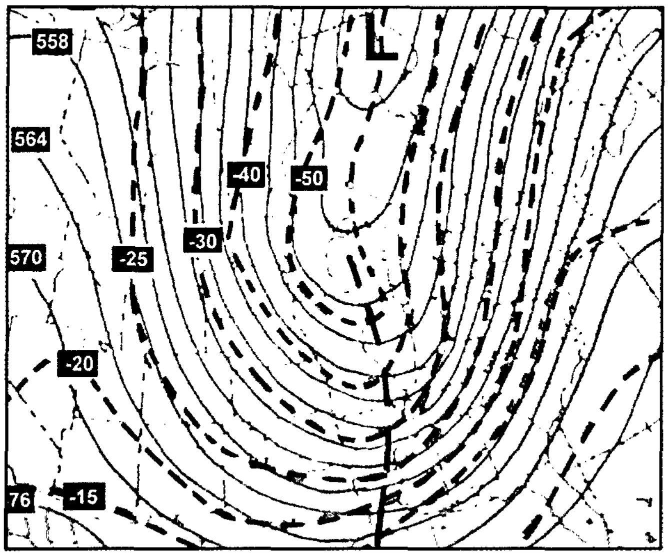

Figure 5-11. 500 mb, 1200Z/2 February 1981

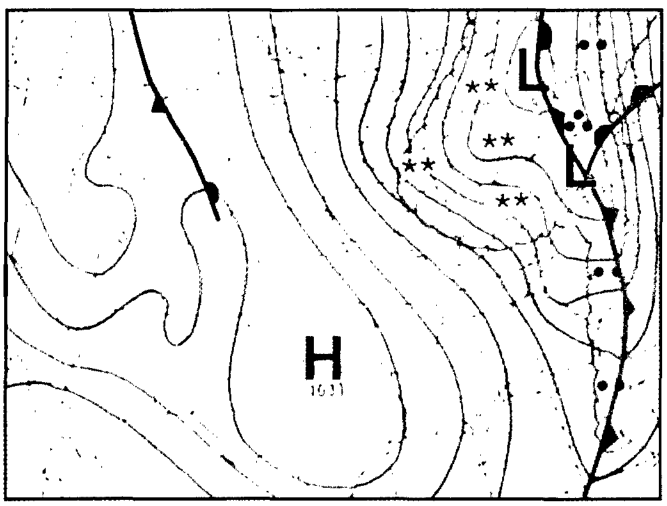

Figure 5-12. Surface, 1200Z/2 February 1981

Figure 5-13, depicts a model event of induced waving as the vorticity comma (B) approaches the baroclinic cloud system (A). In the satellite image (Figure 5-14), the stationary, older baroclinic zone (A) shows signs of induced waving as a comma cloud (B), located across eastern Pennsylvania and West Virginia, approaches the zone.

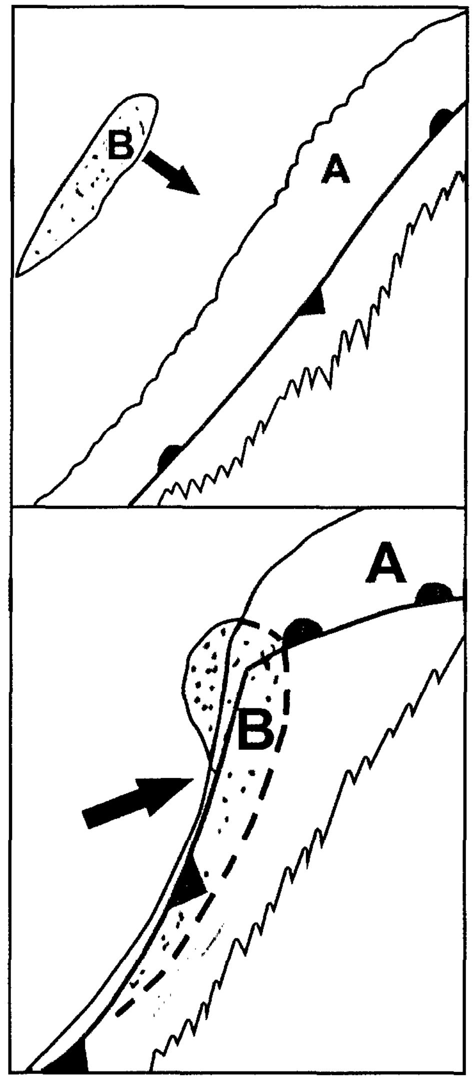

Figure 5-13. Vorticity Comma Approaching the Baroclinic Zone

Figure 5-14. GOES-E VIS, 1425Z/ 2 February 1981
Short wave vorticity comma (B) moving into baroclinic zone (A). Induced waving in the baroclinic zone has occurred (see model in Figure 5-13 noted by the arrow).

Figure 5-15. GOES-E VIS, 1515Z/ 2 February 1981

In the next MetSat image, Figure 5-15, the 500 mb wind reports have been added; the comma cloud is beginning to move underneath the baroclinic zone cloud system. Area **D** shown in Figure 5-15 signifies an area of cold air low-level cloudiness. Several hours later, Figure 5-16, nearly half of the comma system (**B**) has moved under the cirrus deck. This system continued to deepen as it moved off the East Coast.

Figure 5-16. GOES-E VIS, 1846Z/ 2 February 1981

Atlantic Coastal Lows

Atlantic Seaboard storm systems (most often Hatteras Lows) increase throughout the period. Some of these disturbances develop into giant, vicious storms (Nor'easters, Figure 5-17) and bring heavy snows across the interior while heavy rains deluge coastal areas. Although not shown in Figure 5-17, a narrow transition zone of freezing precipitation often occurs a few miles inland while heavy snowfall occurs to the west. Strong northeasterly winds maintain polar air characteristics inland, and with heavy snow falling blizzard-like conditions prevail. Conversely, if the air mass is very cold then snowfall is more likely to the coastal areas.

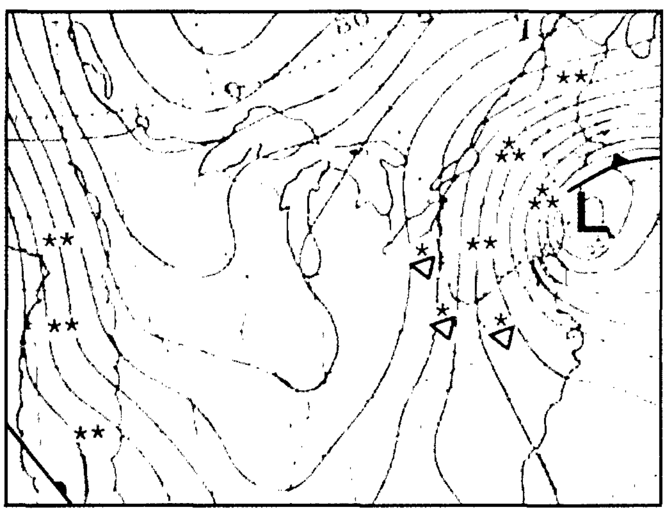

Figure 5-17. Surface, 0000Z/7 February 1978

Coastal lows develop when frontal waves and upper air perturbations interact with strong temperature and moisture discontinuities that exist offshore. These discontinuities are often not discernable on synoptic-scale analyses.

In Figure 5-18, you can see an example of a Midwest storm that has become vertically stacked over the Great Lakes and slowed its eastward progression significantly. These storms begin the slow process of decay, but in the meantime, the triple point of the occlusion has reached the dynamic coastal region. Strong surface temperature and moisture discontinuities, coastal indentations and upper-level support (PVA and cold troughs) supplies the vertical motion to set off the development of a new storm along the Eastern Seaboard. A common development is shown in Figure 5-18. Energy from the old storm in the Great Lakes and energy from the thermal and moisture contrast near the triple point often combine explosively to rake the northeastern CONUS. A favorite breeding ground for triple point development is the DELMARVA (Delaware, Maryland, Virginia peninsula) region as illustrated in Figure 5-18 and more significantly the Cape Hatteras region. If strong pressure falls occur along the front in the DELMARVA region, then suspect that cyclogenesis will develop within the triple point. The occluded segment from the old low to the new low will dissipate. Also, the old low will eventually fill as the new low intensifies.

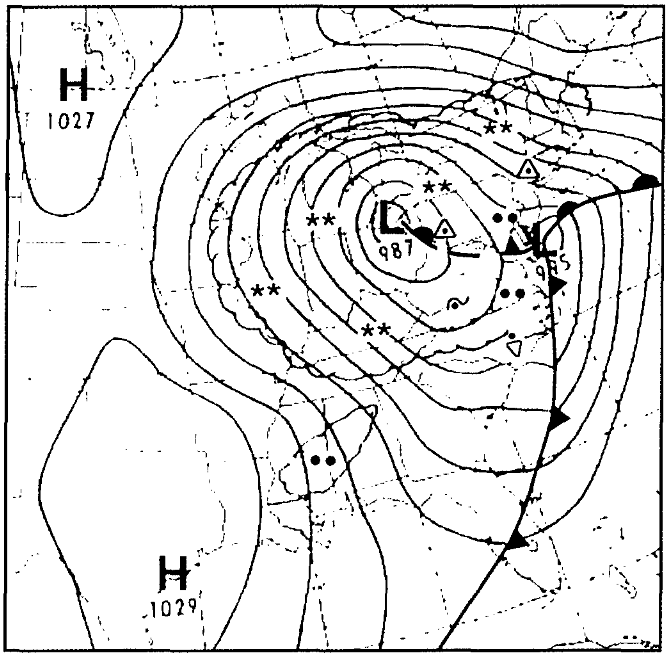

Figure 5-18. Surface, 1200Z/10 January 1977

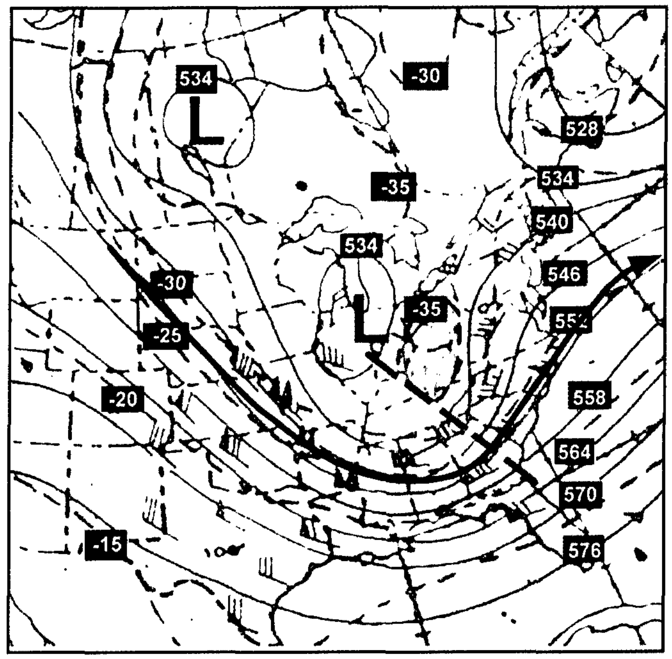

Figure 5-19. 500 mb, 1200Z/6 February 1980

A second example of triple point development (in this case the Cape Hatteras region) supported with satellite data is shown in Figures 5-19 through Figure 5-23. In Figure 5-19, a closed low is shown over the Illinois-Indiana area. The long wave trough was located over this region for several days. A Canadian short wave dropped southward and underwent cyclogenesis within the long wave over the Great Lakes. The short wave has become negatively tilted (axis oriented NW-SE) as it approaches the East Coast. Negative tilt troughs produce the most intense and dynamic storms.

The surface charts, Figures 5-20 and 5-21, depicts low formation and development. The dying low shown over Kentucky in Figure 5-20 is a reflection of the upper low. The occluded front from the low in Kentucky to the coast has dissipated. A new low has formed along the offshore frontal boundary in the vicinity of Cape Hatteras. The Cape Hatteras area is known to breed intense coastal storms that move up the New England coast. Nine hours later in Figure 5-21, the triple point low has deepened off the coast of Virginia.

Figure 5-20. Surface, 1500Z/6 February 1980

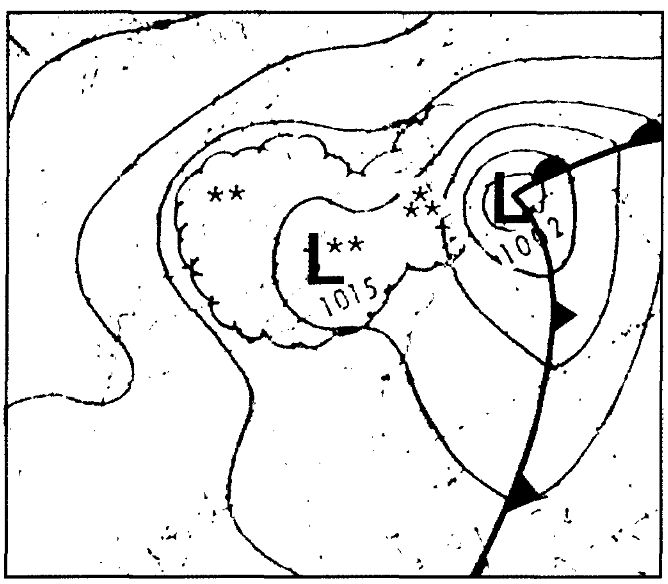

Figure 5-21. Surface, 0000Z/7 February 1980

Satellite data (Figures 5-22 and 5-23), approximately the same time as Figure 5-20, illustrates the developing coastal low over Virginia and North Carolina. In the IR photo (Figure 5-23), maximum tops (and heaviest snow) are shown with the coastal low and lower cloud tops (and lighter snow) are associated with the decaying cyclonic circulation over the Ohio Valley and Great Lakes region. Notice in Figure 5-23, the darker, higher cloud system has taken on the appearance of a vorticity comma cloud and reflects a positive vorticity maximum which will support further intensification of the coastal storm. In Figure 5-22, there is a noticeable V-shape notch (surge region) in the comma system (A) over eastern South Carolina - this notch is where the jet stream is entering the comma system.

Figure 5-22. GOES-E VIS, 1546Z/ 6 February 1980

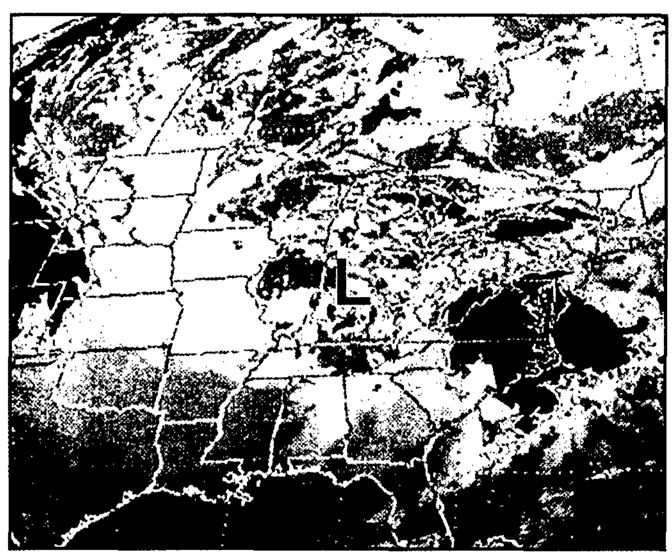

Figure 5-23. GOES-E Enhanced IR, 1446Z/ 6 February 1980

Blocking Highs

As in the case over Alaska, blocking highs also occasionally appear over Greenland and westward towards Canada as shown in Figures 5-24 and 5-25. Consequently, storm systems over the East Coast have a tendency to either slow down offshore or move eastward south of New England. This regime may last for several days. Additionally, the central CONUS would remain under a stagnant anticyclonic pattern.

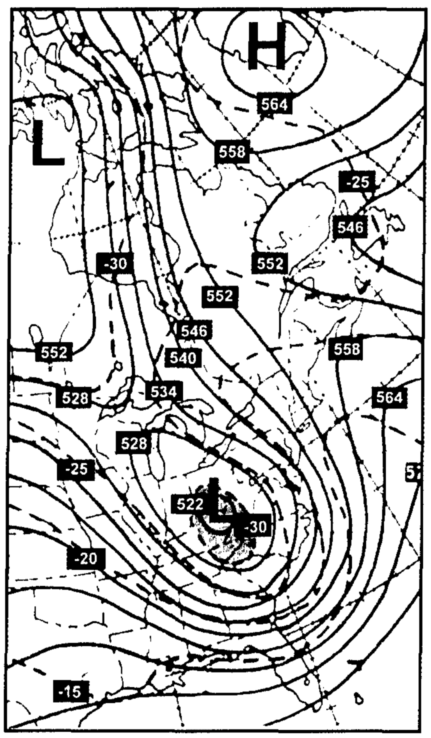

Figure 5-24. 500 mb, 0000Z/25 January 1979

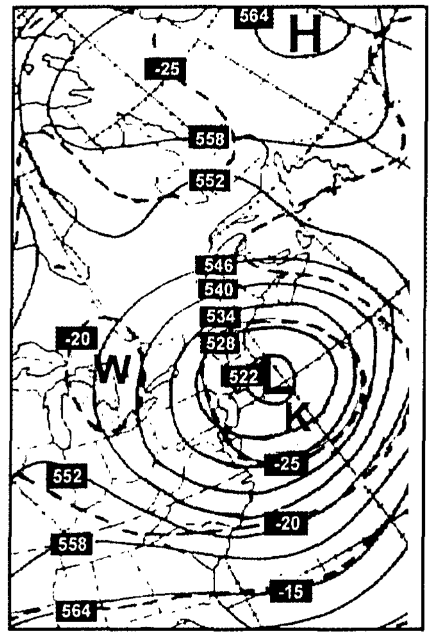

Figure 5-25. 500 mb, 0000Z/26 January 1979
24 hours later than Figure 5-24.

The blocking action produces tighter pressure gradients across New England as the low attempts to move northeastward (Figure 5-26). As a result, strong southeasterly winds from the Atlantic Ocean advects warm air into the disturbance and eventually changes ongoing heavy snow into freezing rain or rain (warm air may circulate into the western and southwestern sectors of the large cyclonic system (Figure 5-27).

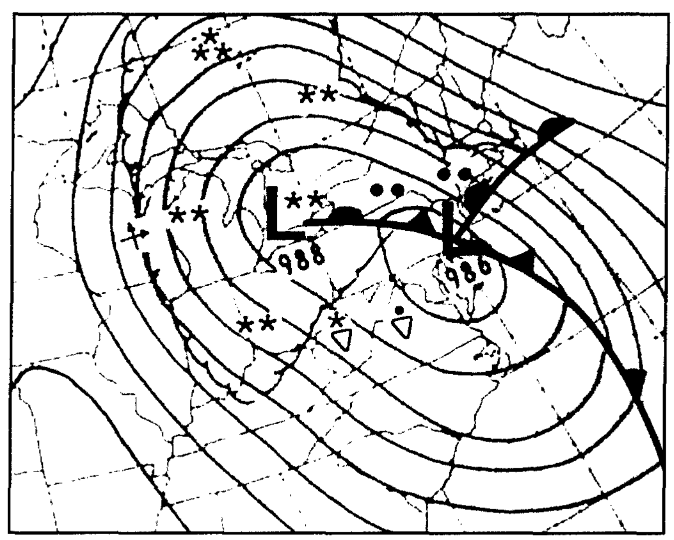

Figure 5-26. Surface, 0000Z/25 January 1979
Triple-point cyclogenesis has developed.

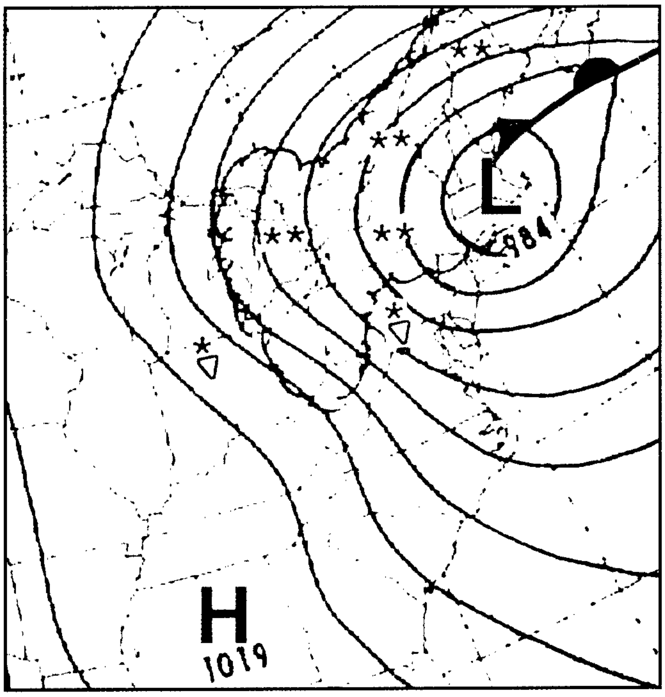

Figure 5-27. Surface, 0000Z/26 January 1979
24 hours later than Figure 5-26.

Another significant coastal storm that occurred on 24-25 January 2000 is included. Moderate to heavy snow fell from the Carolinas to New England. Snowfall was reported all the way to the coastal areas with the greatest amounts further inland. This storm had intensified over the Cape Hatteras area. In hindsight, this was an intense negative-tilt short wave that tracked due north on the front side of the long wave that was located over the Great Lakes to the Gulf Coast. The forecast models had some difficulty on the forecast storm track. Figures 5-28 and 5-29, respectively, show the synoptic conditions 24 hours prior to explosive intensification over the Cape Hatteras region. In Figure 5-29, a stationary front lies off the East Coast across northern Florida. A frontal wave (East Gulf Low) has developed. The thickness field reveals a trough west of the low approaching Florida. As in many coastal storms, warm Atlantic air usually advects westward into these systems, and rain will generally occur along the coast. In this storm, an elongated polar ridge was in place over the eastern CONUS and apparently no appreciable warm air advected inland. Advection was mostly neutral. Figures 5-30 and 5-31 show synoptic conditions 24 hours later.

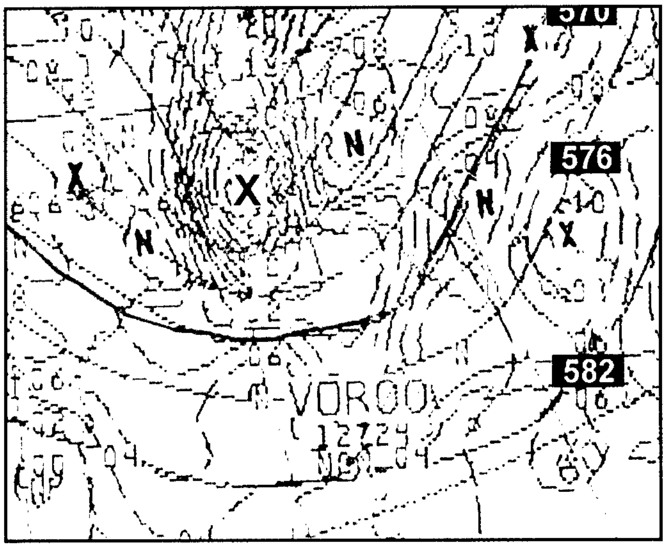

Figure 5-28. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/24 January 2000

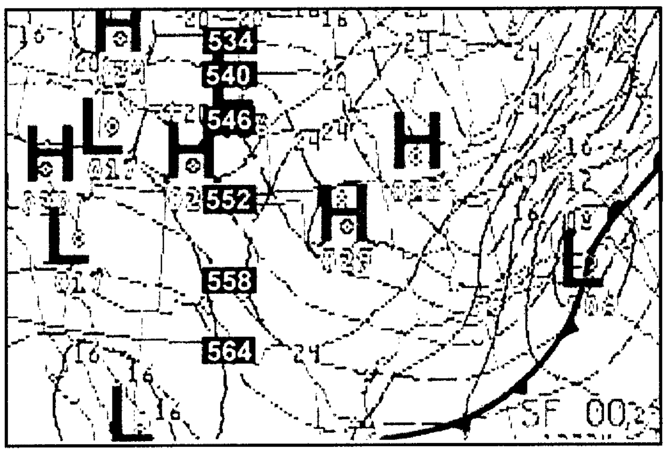

Figure 5-29. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/24 January 2000

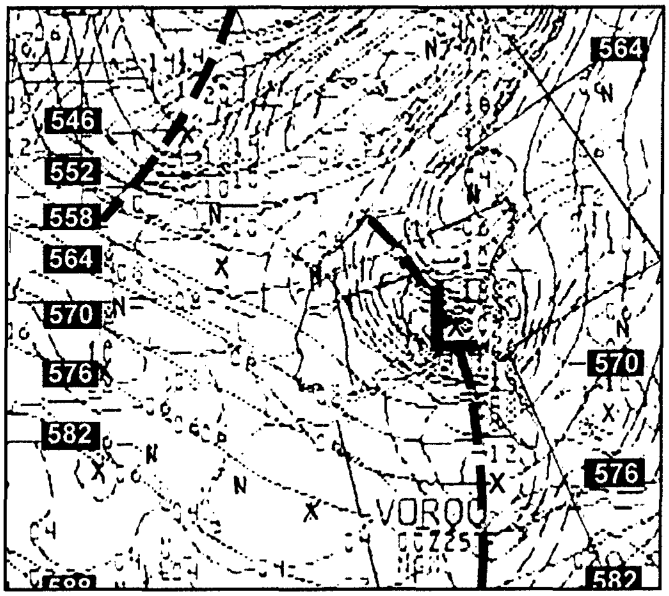

Figure 5-30. 00HR 500 mb HEIGHTS/VORTICITY, 0000Z/25 January 2000
Negative-tilt short wave appears over the southeastern CONUS.

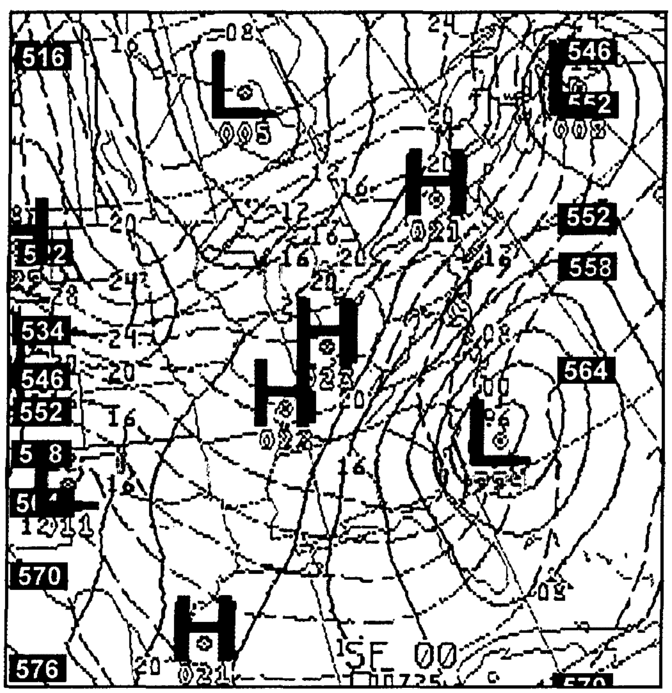

Figure 5-31. 00HR MSL PRES/1000-500 mb THKNS, 0000Z/25 January 2000
Coastal low deepening off of the Carolinas.

Figures 5-32 through 5-33 respectively show the 12-hour 500 mb and surface NGM forecasts. The storm was forecast to hug the coastline all the way to New England. Figures 5-34 and 5-35 are included to compare actual surface conditions and satellite at 1200Z with the 12-hour forecasts shown in Figures 5-32 and 5-33.

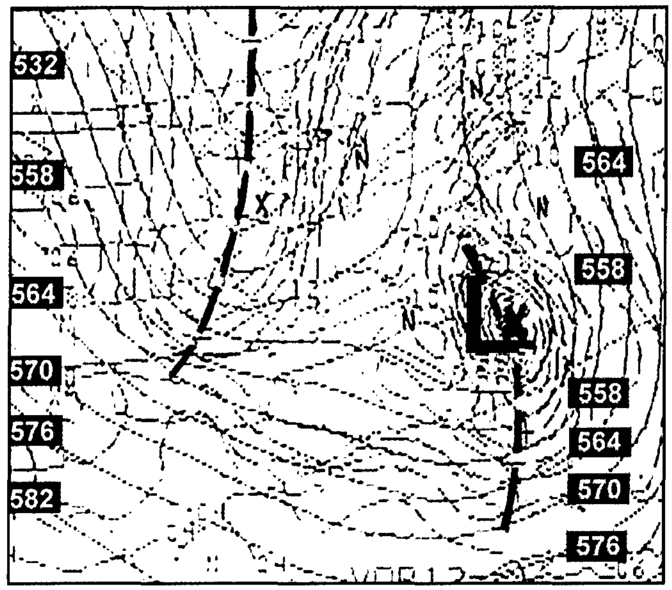

Figure 5-32. 12HR FCST, 500 mb HEIGHTS/VORTICITY, 1200Z/25 January 2000

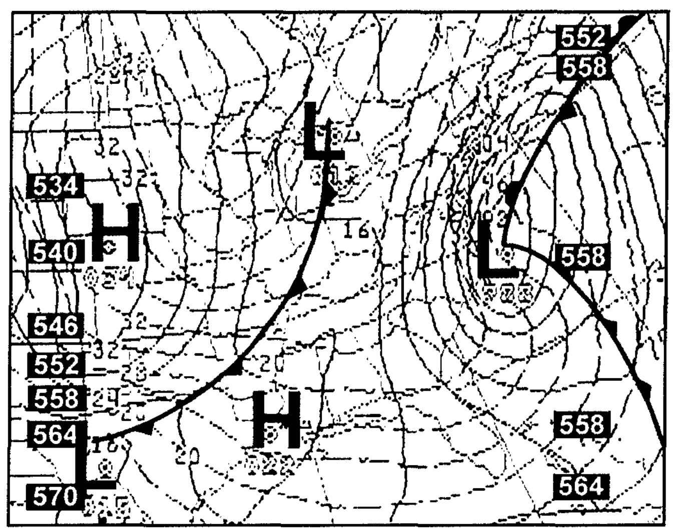

Figure 5-33. 12HR, MSL PRES/1000-500 mb THKNS, 1200Z/25 January 2000

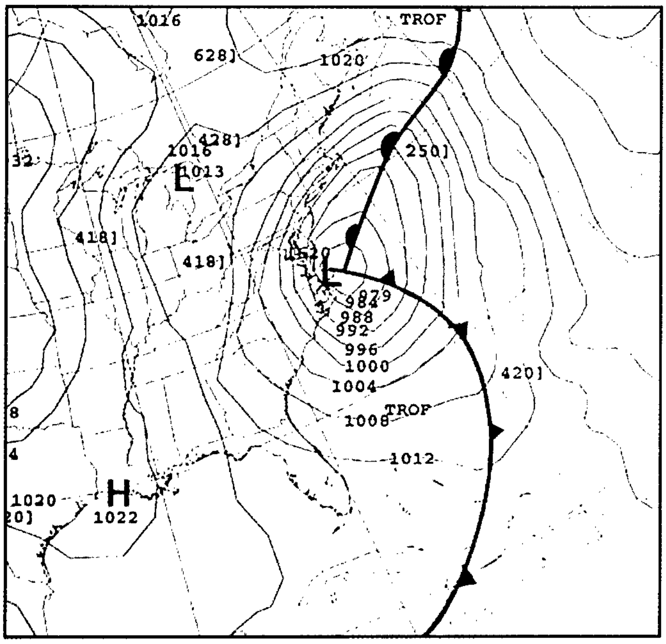

Figure 5-34. Surface, 1500Z/25 January 2000
Low located along North Carolina coast, which is a little closer to the coast than the 12-hour forecast shown in Figure 5-33.

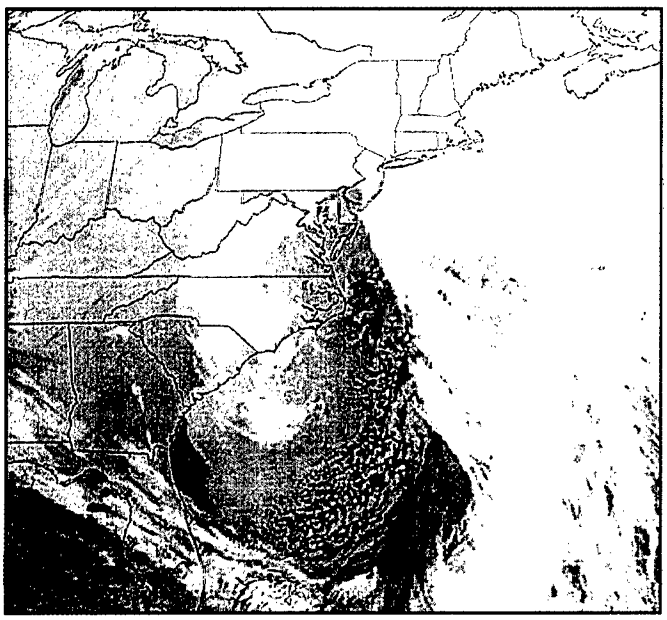

Figure 5-35. GOES-E IR, 1215Z/ 25 January 2000
Deformation cloud system shown from Pennsylvania to Georgia. Moderate to heavy snowfall occurred.

The 24-hour NGM forecasts are shown in Figures 5-36 and 5-37. In Figure 5-37, the surface low is forecast to move northward just off the coast. The 500 mb 24-hour forecast, Figure 5-36, shows that the storm appears as an intense short wave (small dashed lines) lifting northward on the east side of the long wave (larger dashed lines). Enhanced multichannel satellite images (visible and IR combined) shown in Figures 5-38 and 5-39 are courtesy of NOAA OSEI archive.

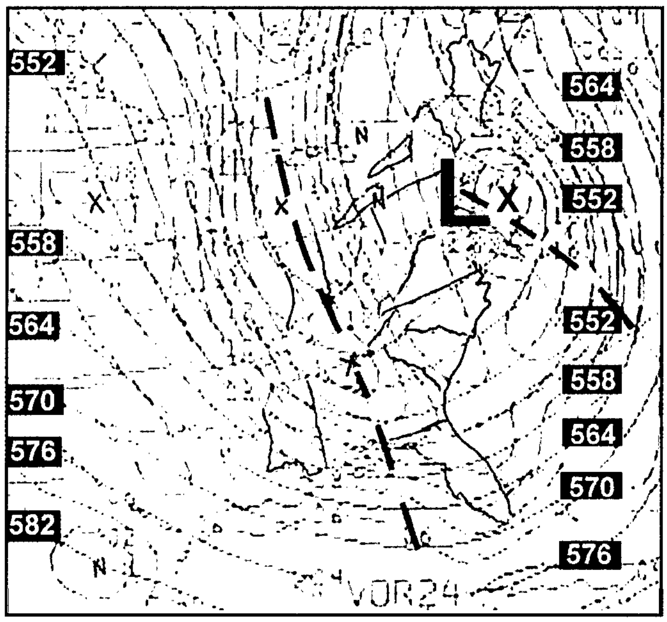

Figure 5-36. 24HR 500 mb HEIGHTS/VORTICITY, 0000Z/26 January 2000

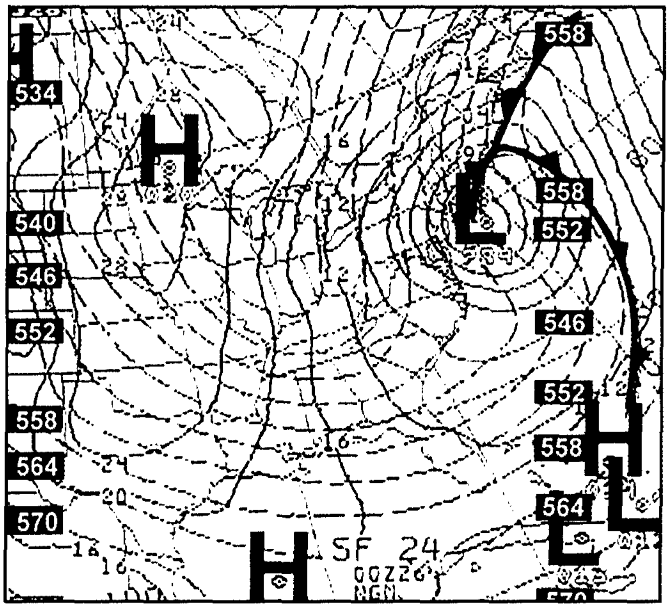

Figure 5-37. 24HR, MSL PRES/1000-500 mb THKNS, 0000Z/26 January 2000

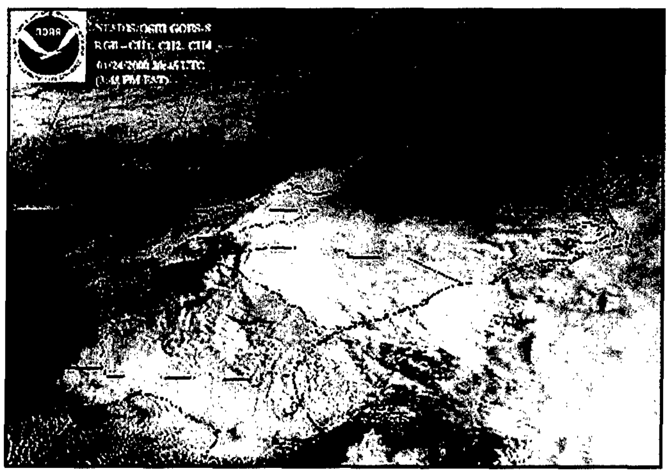

Figure 5-38. GOES-E Multi-Channel, 2045Z/ 24 January 2000

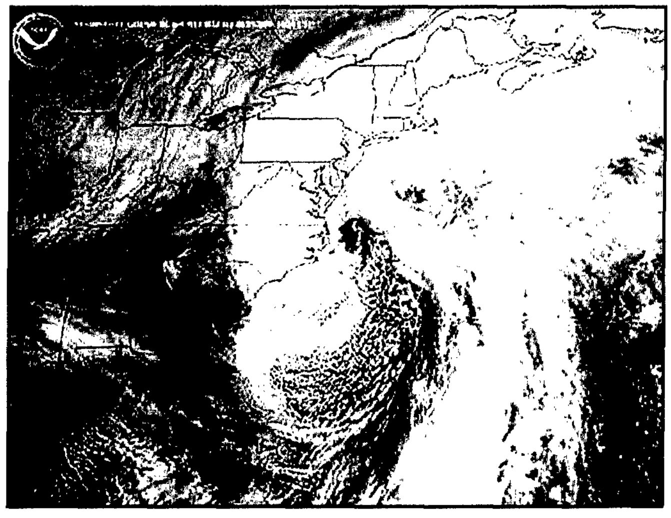

Figure 5-39. GOES-E Multi-Channel, 2100Z/ 25 January 2000
Approximately 24-hours later than Figure 5-38. Notice how intense this coastal storm has become.

Lower Mississippi Valley – Example 1

Another prime region for cyclogenesis and/or intensification of lows that produce winter storms over the Great Lakes and northeastern CONUS is the Lower Mississippi Valley and the Gulf of Mexico. Generally, a long wave trough is located over the Great Plains. Short waves move into the long wave over the Southern Plains and recurve over the Lower Mississippi Valley region. Several examples will now be shown.

Polar frontal cyclogenesis associated with a prevailing high (Alberta High) regime, as pictured in Figure 5-41, spread rain, snow and freezing precipitation across an extensive area of the central and eastern CONUS. This developing storm (Texas Low) was located close to the source of Gulf moisture. An approaching short wave system from the southern Rockies (Figure 5-40), moving through the long wave, strengthened cyclogenesis. Forecasters across Missouri, Illinois and Great Lakes must watch for signals of storm recurvature towards the northeast. In this example, the short wave lifted northeastward over the Lower Mississippi Valley.

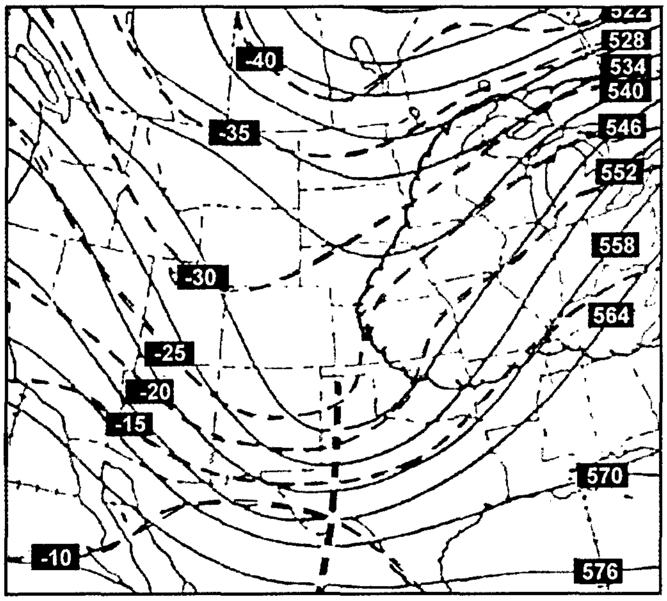

Figure 5-40. 500 mb, 1200Z/13 January 1978

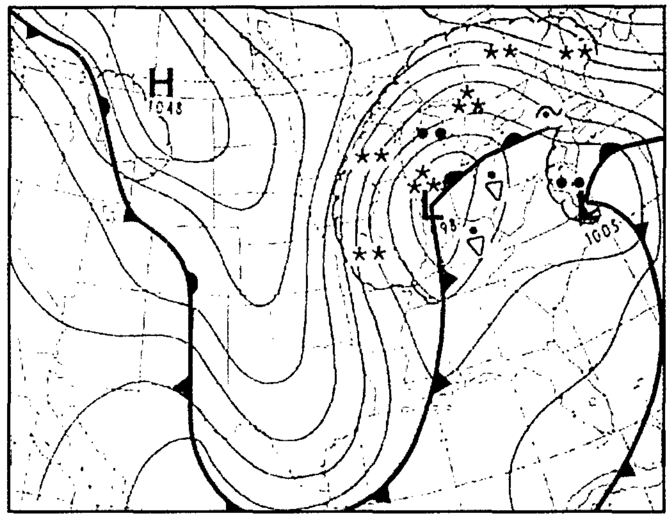

Figure 5-42. Surface, 1200Z/14 January 1978
Texas Low shown in Figure 5-41 over northeast Texas has deepened and moved northward into the Great Lakes region.

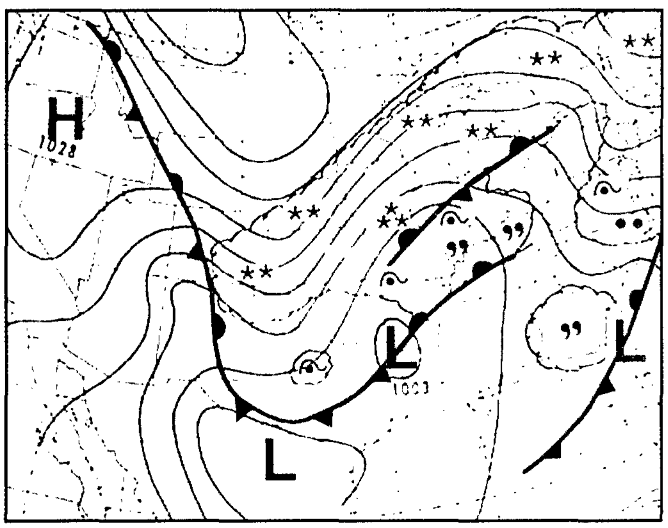

Figure 5-41. Surface, 1200Z/13 January 1978

System intensification is rapid after recurvature and those locations that lie along the cold side of the storm's path will experience light to moderate snowfall changing to heavy snow accompanied by strong winds (Figure 5-42).

Lower Mississippi Valley – Example 2

This example is included to advise forecasters that a major severe thunderstorm event will occur during the winter when all the ingredients are established. These major events are likely when Southern Plains/ Lower Mississippi Valley storm systems recurve northeastward across the central CONUS (polar high recedes to the East Coast). The air mass ahead of the developing storm destabilizes as warmer air and Gulf moisture advects northward. In Figure 5-43, the primary low is shown over western Oklahoma with a frontal boundary extending from the low across northern Texas and Louisiana and eastward to North Carolina. Severe thunderstorms developed along and south of this boundary over northeastern Texas and northern Louisiana during the afternoon of 23 January 1997. Note: Upper-air data was not included, but the reader can surmise where the upper trough lies by looking at each panel's thickness fields.

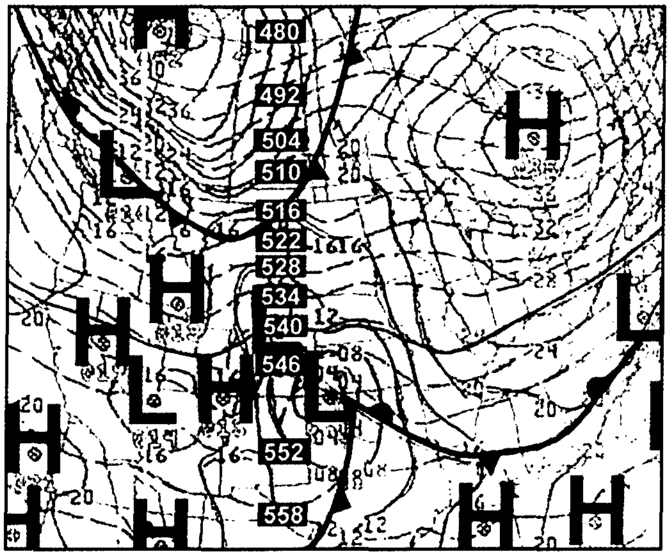

Figure 5-43. 00HRMSL PRES/1000-500 THKNS, 0000Z/24 January 1997

Figures 5-44 through 5-46 respectively illustrate the 12-hour through the 36-hour NGM forecasts that verified well. The Texas Low coming out of the Southern Plains shown in Figure 5-43 recurved over Arkansas (Figure 5-44) and was located over Indiana within the next 12 hours (Figure 5-45). Cold frontal thunderstorms increased rapidly over the southeastern CONUS as the low lifted northward (Figures 5-45 and 5-46). A fresh outbreak of cP air from the northern Great Plains fed into the storm system as it lifted northward (Figure 5-46).

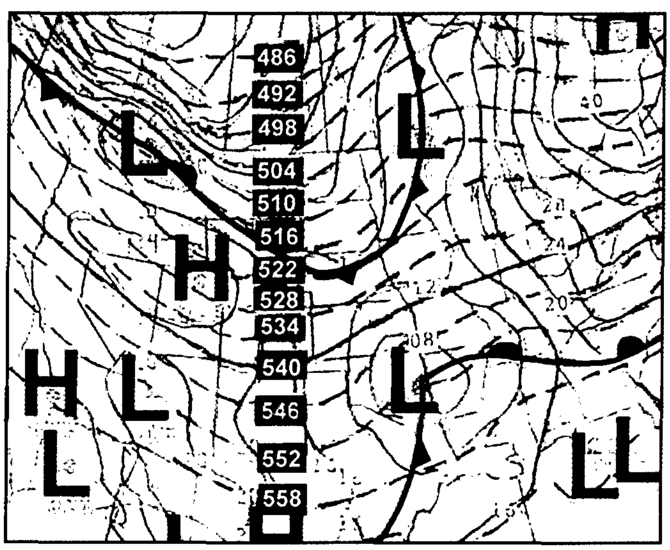

Figure 5-44. 12HR MSL PRES/1000-500 THKNS, 1200Z/24 January 1997

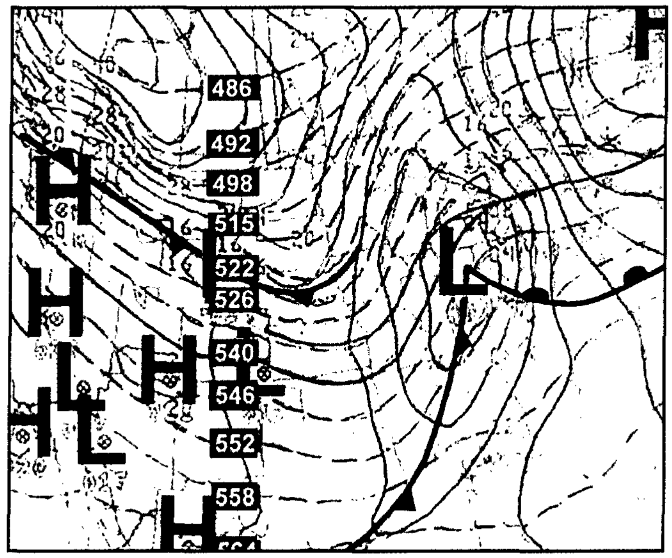

Figure 5-45. 24HR MSL PRES/1000-500 THKNS, 0000Z/25 January 1997

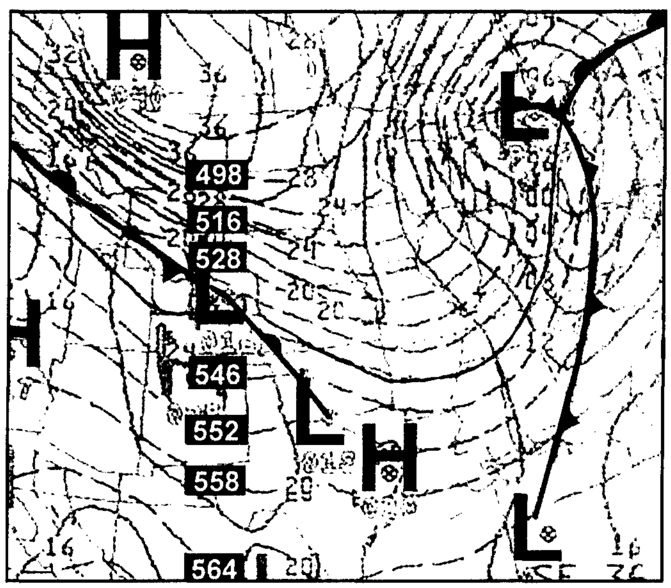

Figure 5-46. 36HR MSL PRES/1000-500 THKNS, 1200Z/25 January 1997

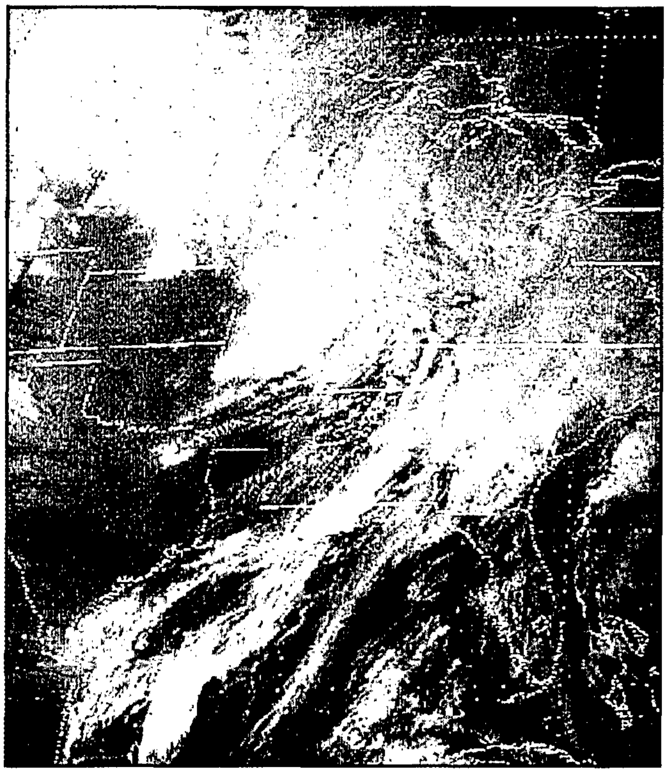

Figure 5-47. GOES-E VIS, 2145Z/ 24 January 1997

The visible satellite image, Figure 5-47, reveals the developing severe frontal thunderstorm line approximately two hours prior to the 24-hour forecast shown in Figure 5-45.

Several hours prior to the 24-hour forecast shown in Figure 5-45, a severe thunderstorm outbreak occurred (see Figures 5-49 through 5-51).

The following figures depict the severe weather that occurred during the afternoon and evening of 24 January 1997. These reports were received at AFWA's Severe Weather Unit. All tornado reports received were plotted as shown in Figure 5-51. Not all reports received for hail, convective gusts and wind damage were plotted in Figures 5-49 and 5-50 due to data congestion.

Severe Thunderstorm Symbols

- ▲ Hail ≥ 3/4"
- ■ Wind Damage
- ● Convective Gusts ≥ 50 Knots
- ▼ Tornado

Figure 5-48. Severe Thunderstorm Symbols

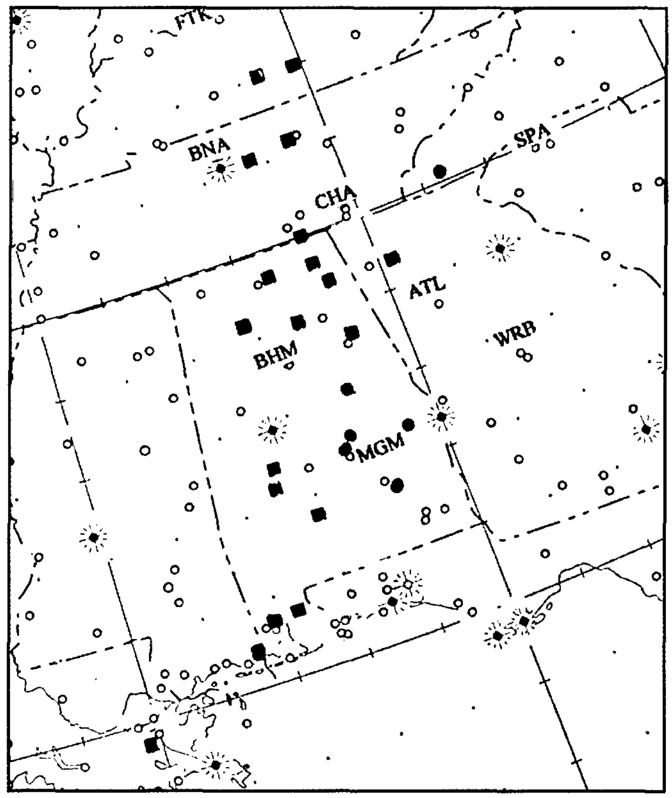

Figure 5-49. Wind Damage and Convective Reports, 24 January 1997

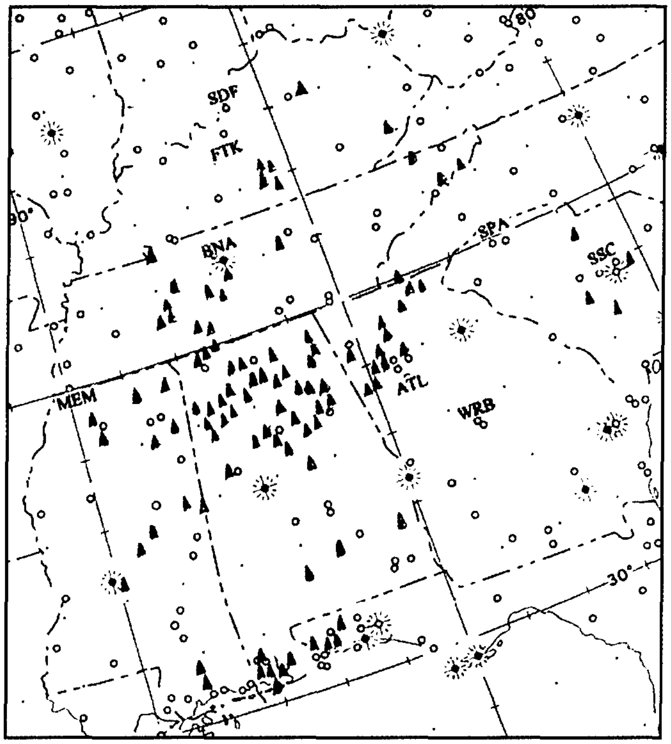

Figure 5-50. Hail = ¾" Reports, 24 January 1997

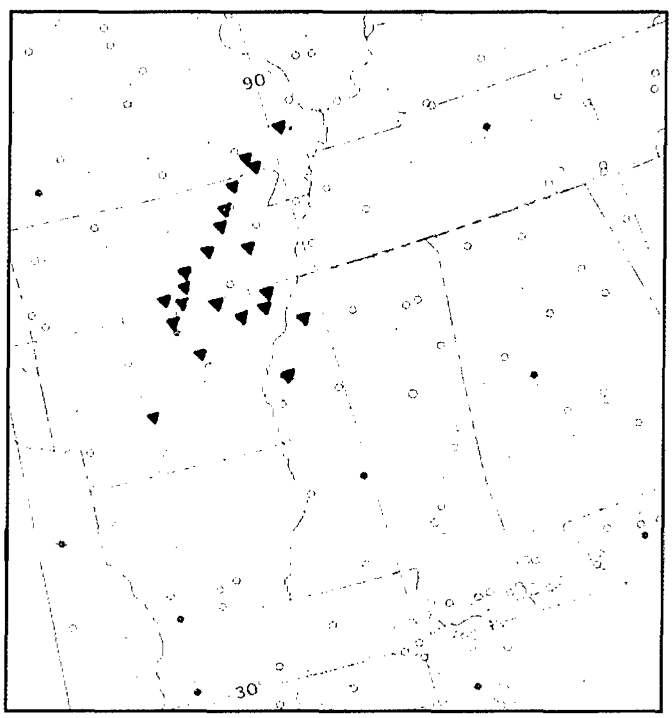

Figure 5-51. Tornado Reports, 24 January 1997

Lower Mississippi Valley – Example 3

The second example is shown in Figures 5-52 through 5-59c. This synoptic regime produces a variety of winter weather over a large area of the Midwest. In Figure 5-52, the long wave lies over the Great Plains. A short wave has bottomed out within the long wave over northern Texas. In Figure 5-53, two frontal lows appeared over Illinois and northern Texas. The Texas Low should become the primary low and stacks with the developing upper low over western Texas shown in Figure 5-52. Warm air and Gulf moisture has advected into the storm system. This storm system produced several days of tornadoes across the Southland.

In Figures 5-54 through 5-57, the 12 and 24 hour NGM 500 mb and surface forecasts are shown. The visible satellite image, Figure 5-58, depicts severe thunderstorms activity across the central CONUS approximately 14 hours prior to Figures 5-53 and two hours and twenty minutes earlier than Figure 5-59a. The tornado reports shown in Figure 5-59a through 5-59c depict tornado reports associated with this developing storm.

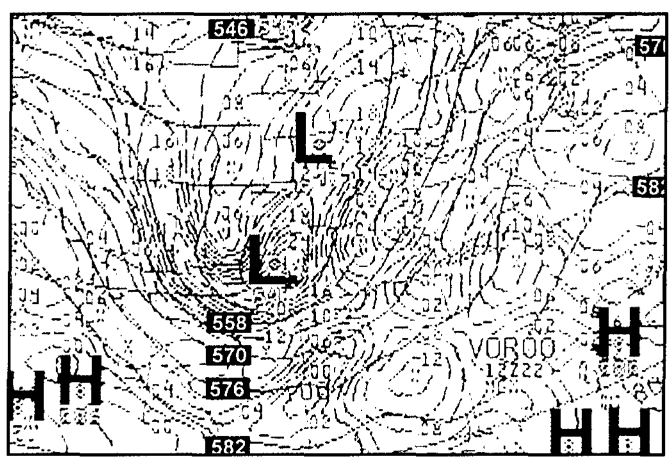

Figure 5-52. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/22 January 1999

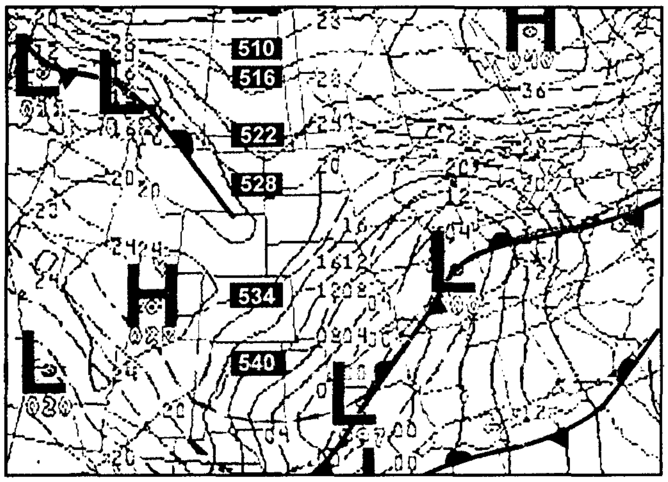

Figure 5-53. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/22 January 1999

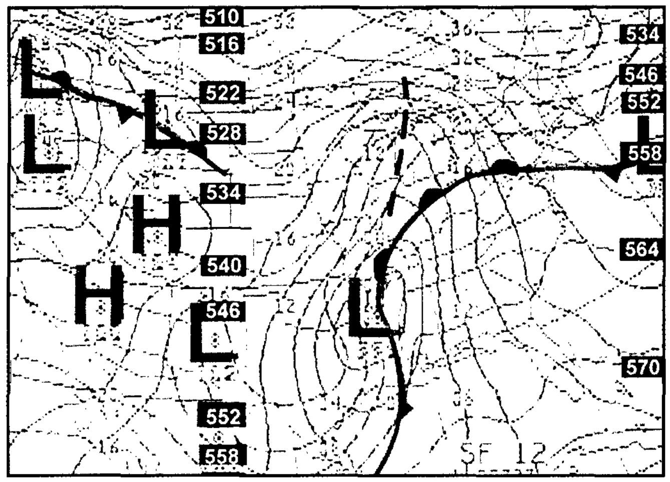

Figure 5-55. 12HR FCST, MSL PRES/1000-500 mb THKNS, 0000Z/23 January 1999
Low over Arkansas stacks with upper-level low.

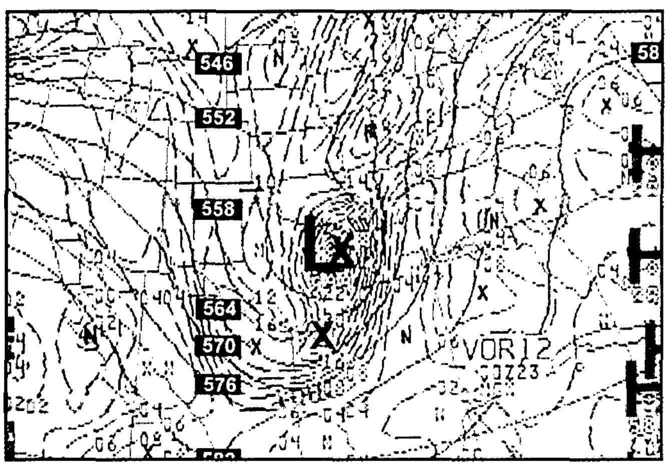

Figure 5-54. 12HR 500 mb HEIGHTS/VORTICITY, 0000Z/23 January 1999
Developing low within base of the long wave.

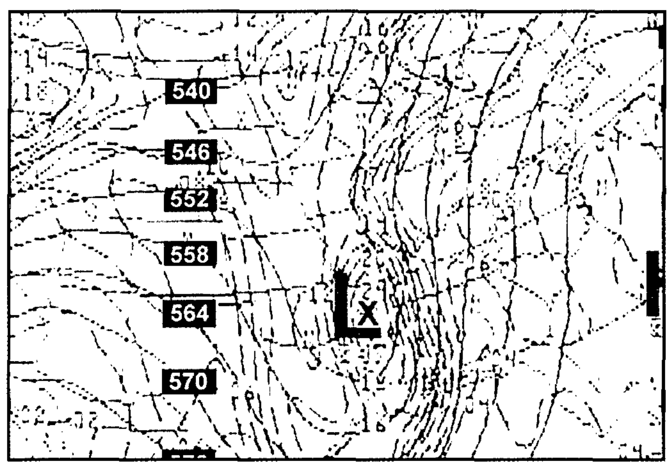

Figure 5-56. 24HR 500 mb HEIGHTS/VORTICITY, 1200Z/23 January 1999

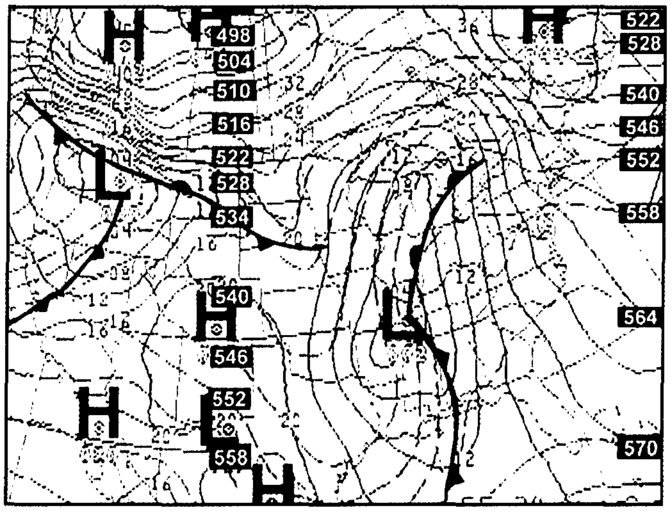

Figure 5-57. 24HR MSL PRES/1000-500 mb THKNS, 1200Z/23 January 1999

Southerly winds brought warm air and Gulf moisture northward to southern Canada.

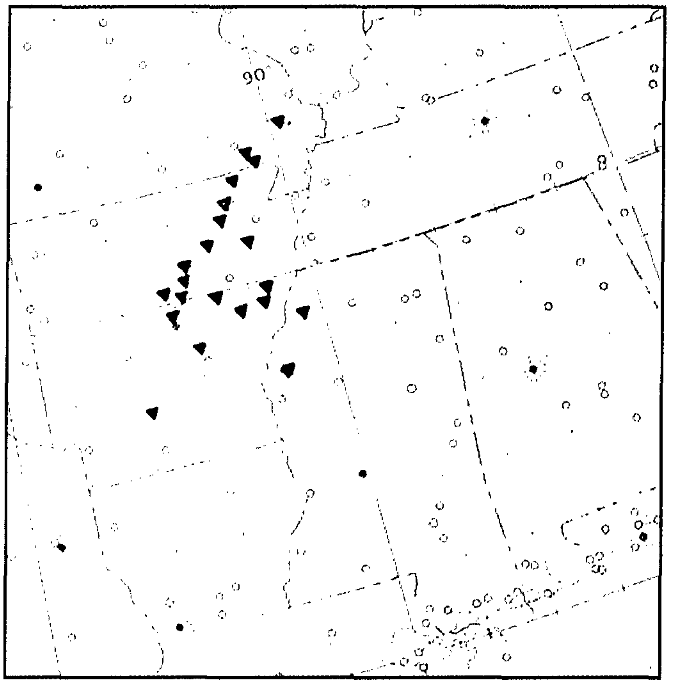

Figure 5-59a. Tornado Reports, 21/1200Z – 22/0000Z January 1999

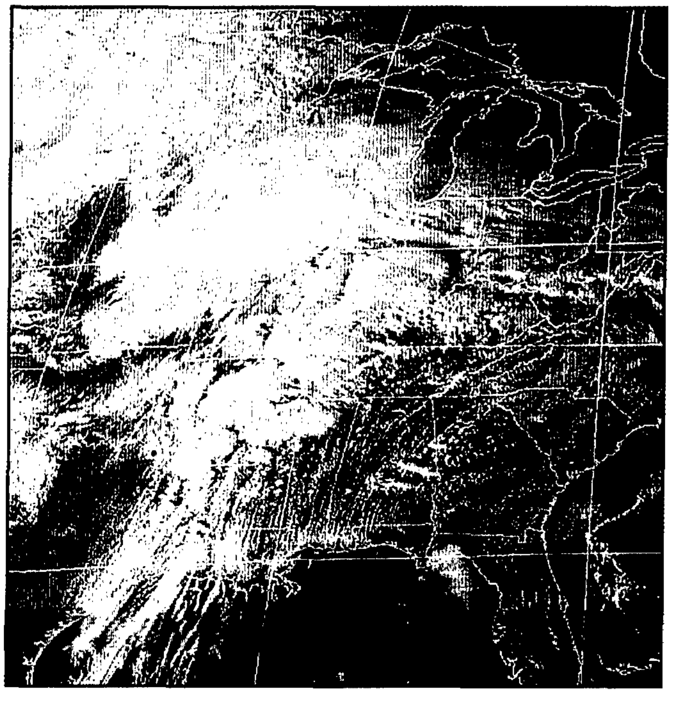

Figure 5-58. GOES-E VIS, 2140Z/ 21 January 1999

Severe thunderstorms and tornadoes occurring across the Lower Mississippi Valley.

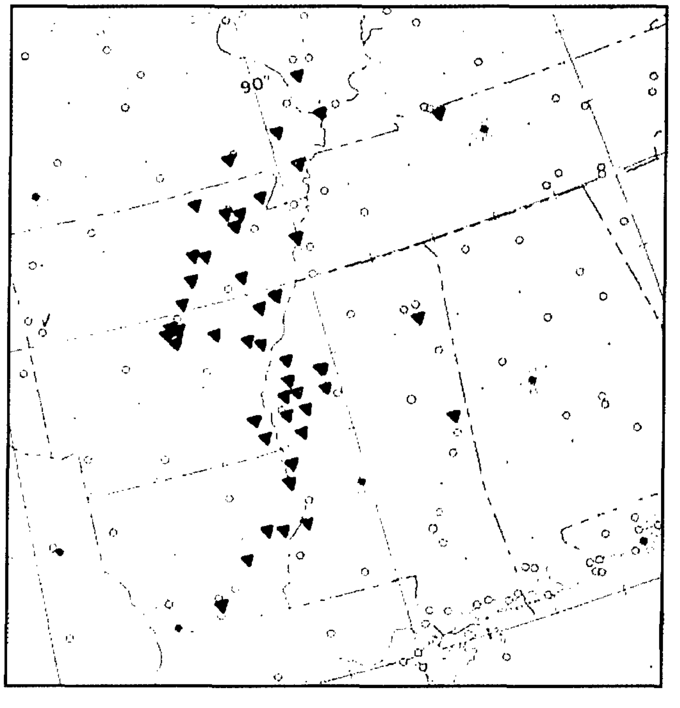

Figure 5-59b. Tornado Reports, 22/0000Z – 22/1200Z January 1999

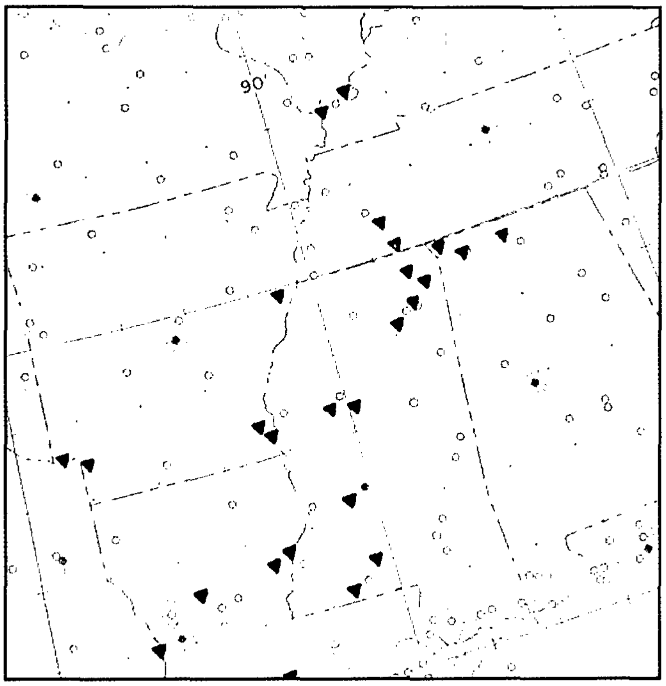

Figure 5-59c. Tornado Reports, 22/1200Z – 23/0000Z January 1999

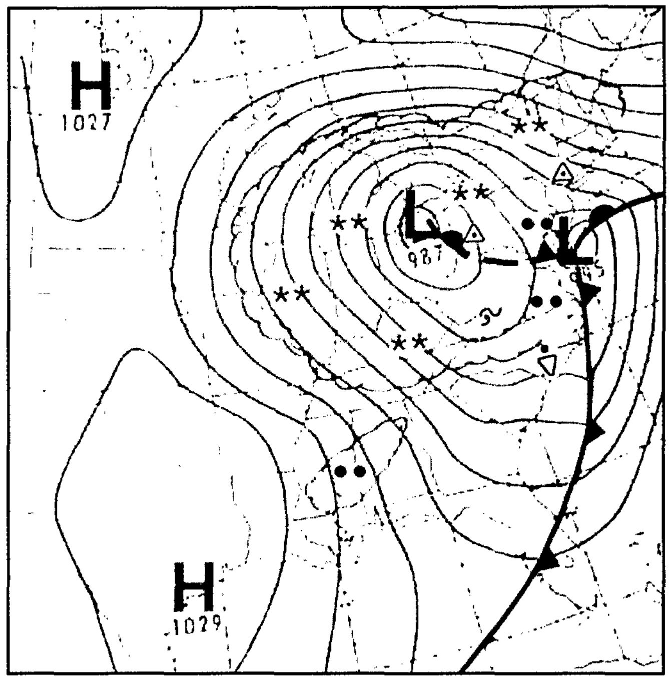

Figure 5-60. Surface, 1200Z/10 January 1977

Slow-Moving Lows

Low-pressure systems that organize and deepen over the southern Great Plains and/or Lower Mississippi Valley regions often become mature occluded systems over the Great Lakes. These vertically stacked systems may "hang up" over the Great Lakes region while a new low may form at the triple point off of the Atlantic Seaboard (Figure 5-60). These slow-moving systems may remain over the Great Lakes area for days. Low clouds within this cyclonic flow often produces light snow showers and more intense lake effect snows in the snow belt areas or periods of light freezing drizzle especially during the nocturnal period across the Great Lakes and into western Pennsylvania and New York as depicted in Figure 5-61. Figures 5-62 through 5-63 depict mature comma cloud systems over the Ohio Valley and Great Lakes region.

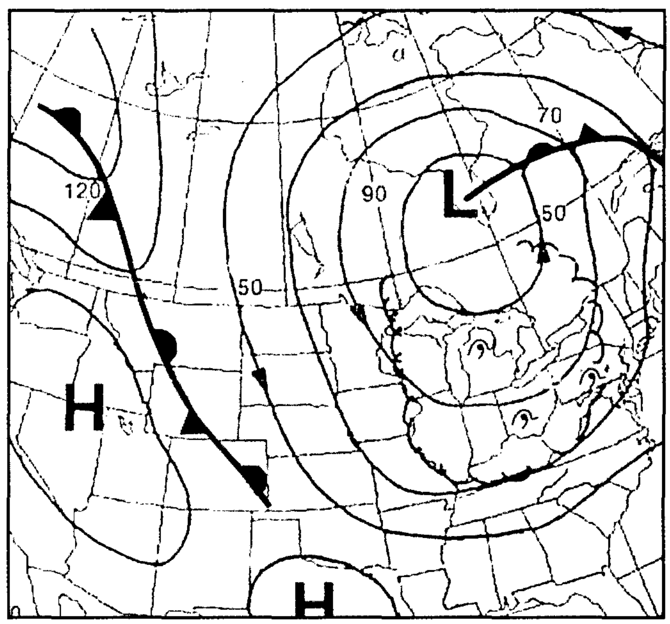

Figure 5-61. Typical Quasi-Stationary Low Situation

Cloudiness and light precipitation over the Great Lakes region.

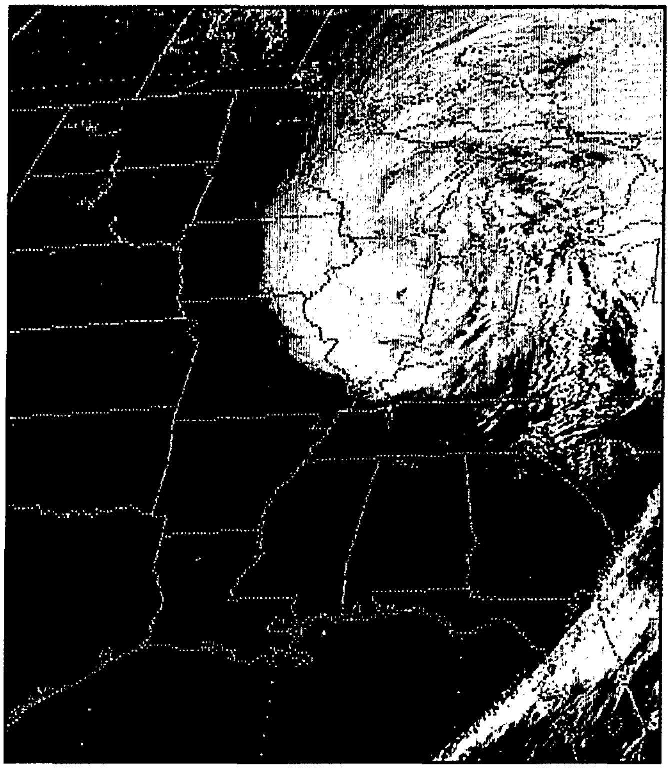

Figure 5-62. GOES-E VIS, 1630Z/ 23 February 1981

Gulf of Mexico Cyclogenesis

Cyclogenesis along polar fronts in the Gulf of Mexico (prevailing high) are often precursors of intense coastal storms that produce heavy snowfall and strong coastal winds (i.e., the superstorm of 13 March 1993 formed southeast of Brownsville, Texas). Figure 5-64 illustrates an example of an East Gulf Low that became a major Eastern Seaboard within 24-hours. Beginning on 19 January 1978, an extensive area of overrunning precipitation spread northward (Figure 5-64) and affected nearly all of the eastern CONUS. Snow, ice pellets (sleet) and freezing precipitation across the Gulf coastal states occurred with this pattern. The appearance of inverted troughing north of the surface low and along the Appalachian Mountains as illustrated in Figure 5-64 generally suggests that the East Gulf Low will move northeast towards the East Coast. This particular case example will be presented more in detail in Chapter 6.

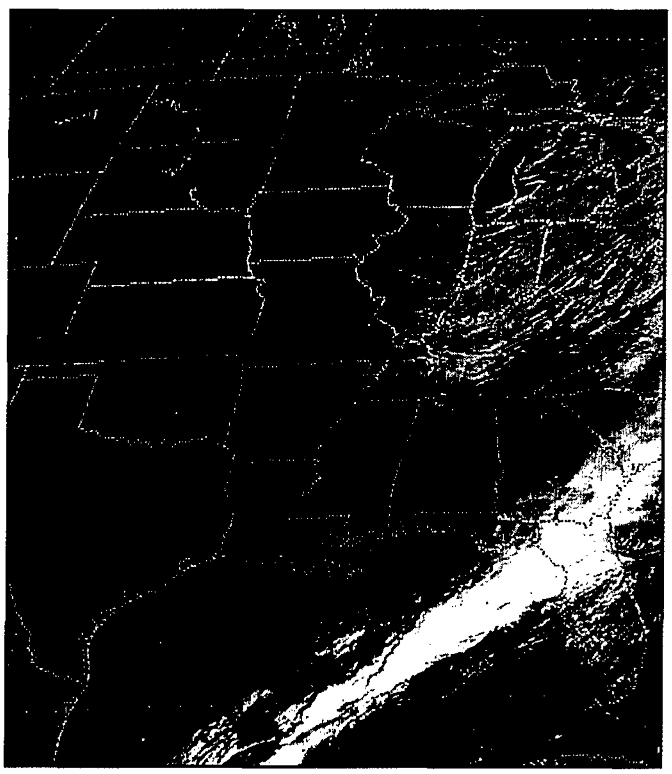

Figure 5-63. GOES-E VIS, 1530Z/ 4 January 1982

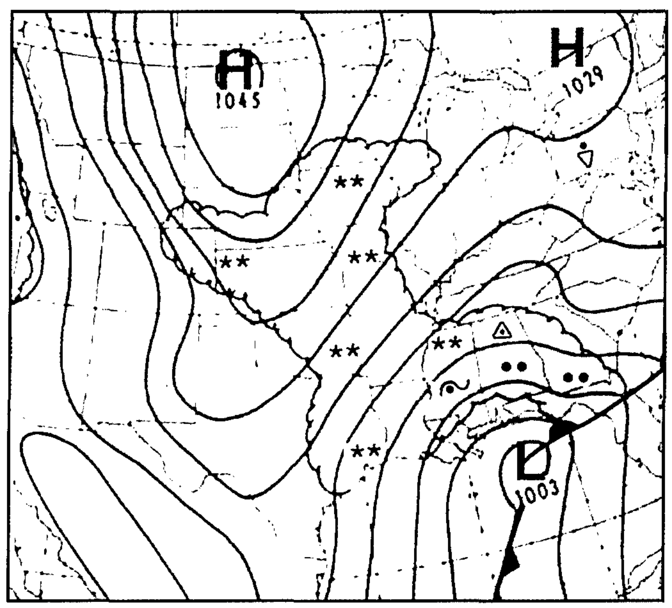

Figure 5-64. Surface, 1200Z/19 January 1978

Several more examples of polar frontal cyclogenesis (prevailing high) within the Gulf of Mexico will be presented. Model guidance is not included. The following event showing a West Gulf Low includes excellent IR images of a developing positive vorticity system over the Gulf of Mexico. This occurred within the lower end of the comma tail associated with a synoptic-scale comma system located over the southern Great Plains. Figures 5-65 and 5-66 respectively depict the 500 mb and surface analyses 12 hours prior to vorticity comma cloud formation. In Figure 5-65, an upper low system is approaching Texas. The surface pattern, Figure 5-66, reveals the presence of an extensive high-pressure zone across the CONUS. Precipitation is occurring from central and west Texas westward to the Rocky Mountains – a reflection of increased PVA ahead of the approaching short wave and low-level upslope flow.

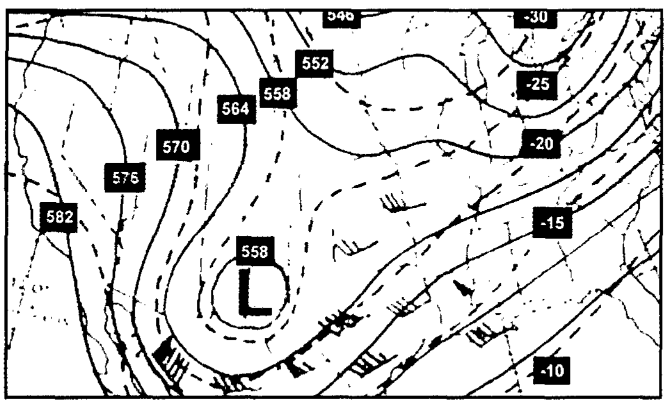

Figure 5-65. 500 mb, 1200Z/25 November 1980

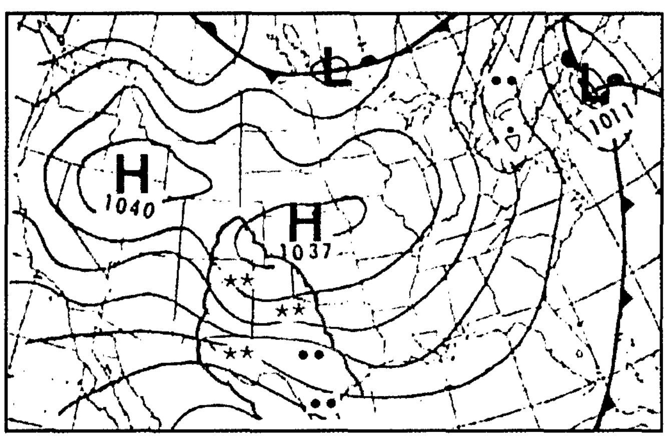

Figure 5-66. Surface, 1200Z/25 November 1980

In the first IR satellite photo of the series, Figure 5-67 (approximately 4 hours prior to comma cloud development and 12 hours later than Figures 5-65 and 5-66), a vorticity center noted at **X** is shown along the southeastern Texas Gulf Coast. The vorticity center is approaching the tail of a developing comma system located across the Southern Plains and Lower Mississippi Valley.

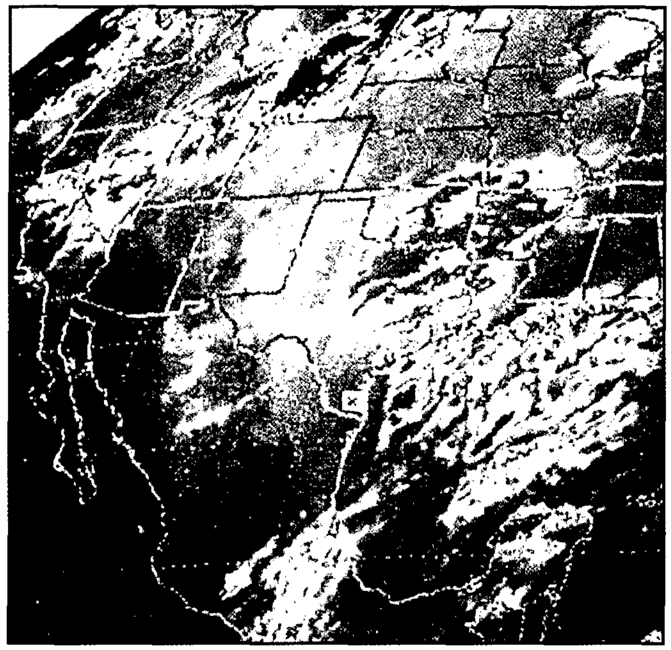

Figure 5-67. GOES-E Enhanced IR, 2346Z/ 25 November 1980

Approximately fours later in Figure 5-68 (note the different enhancement curve), the large area of PVA has become organize and has taken on a comma shape appearance. The apparent circulation center appears to be located over north-central Texas indicated by the **L**; the rotation center noted by the **X** is shown off the Texas coast. The highest cloud tops observed (white in this particular enhancement) are the result of thunderstorm plumes.

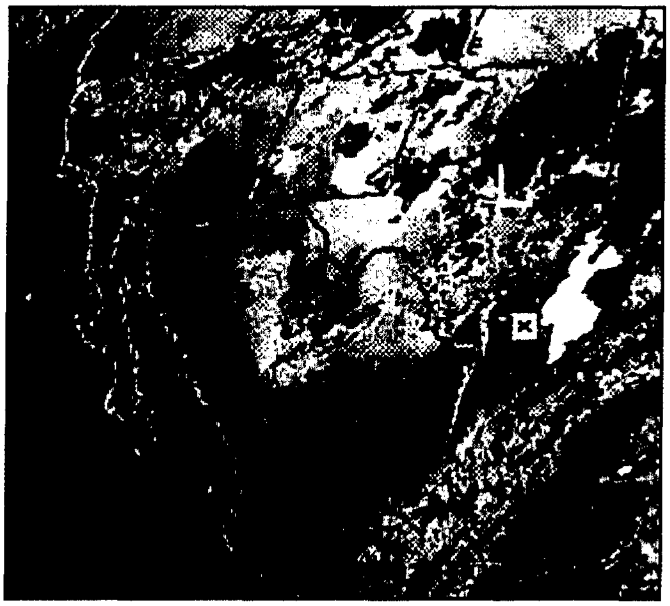

Figure 5-68. GOES-E Enhanced IR, 0316Z/ 26 November 1980

The subsequent series of satellite photos shown in Figures 5-69 through 5-71 reveal the developing vorticity comma cloud system within the comma tail. In Figure 5- 71, cirrus plumes are visible over the eastern end of the comma head. The white arrow shown in Figures 5-69, 5-70 and 5-71 (v-notch) is the jet entrance region

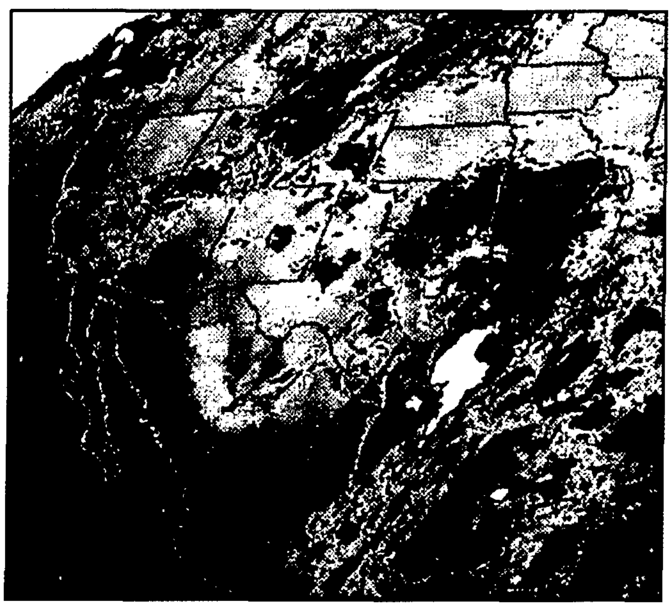

Figure 5-69. GOES-E Enhanced IR, 0346Z/ 26 November 1980

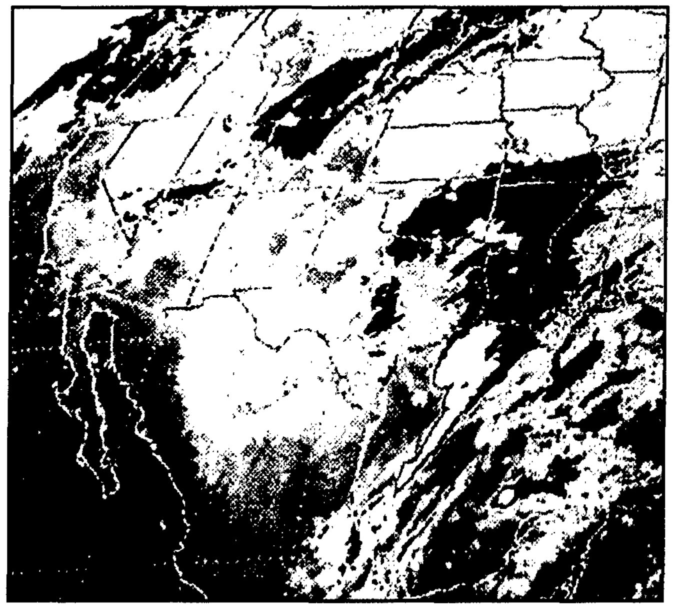

Figure 5-70. GOES-E Enhanced IR, 0416Z/ 26 November 1980

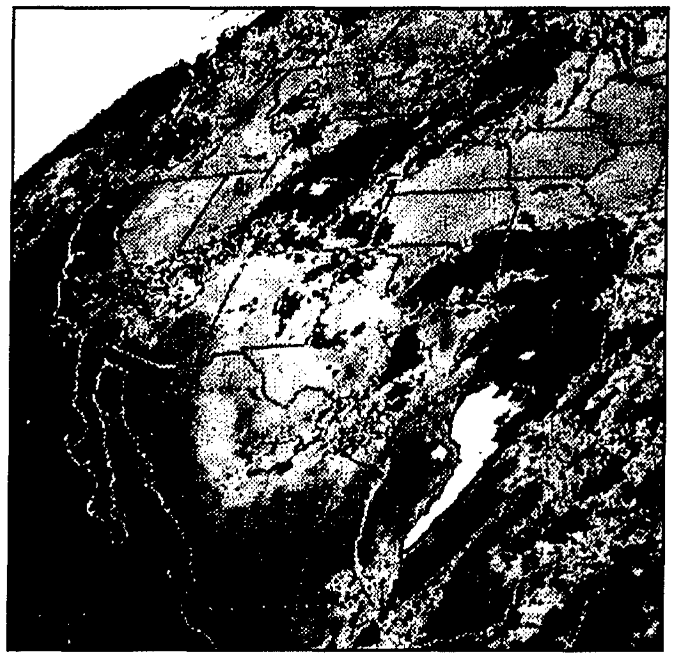

Figure 5-71. GOES-E Enhanced IR, 0516Z/ 26 November 1980

Figures 5-72 and 5-73 respectively depict the 500 mb and surface analyses seven hours after vorticity comma cloud development shown in Figure 5-71. In Figure 5-73, a wave has formed on the polar front and is located underneath the vorticity comma system shown in Figure 5-71. Twenty-four hours later in Figure 5-74, the organized West Gulf Low storm system has moved northeastward into the Ohio Valley region.

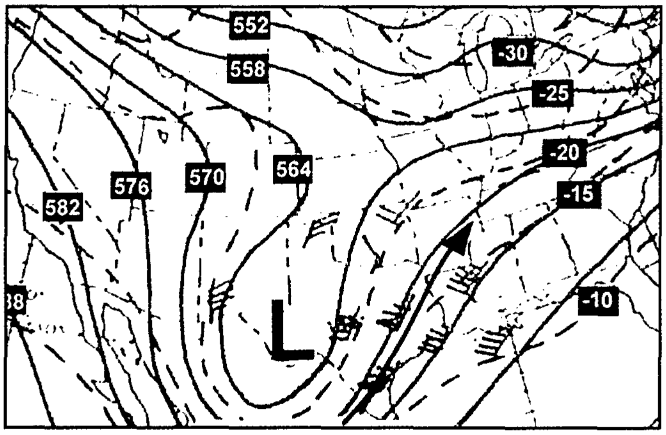

Figure 5-72. 500 mb, 1200Z/ 26 November 1980
Approximately 7 hours later than Figure 5-71. Upper low has moved into west Texas.

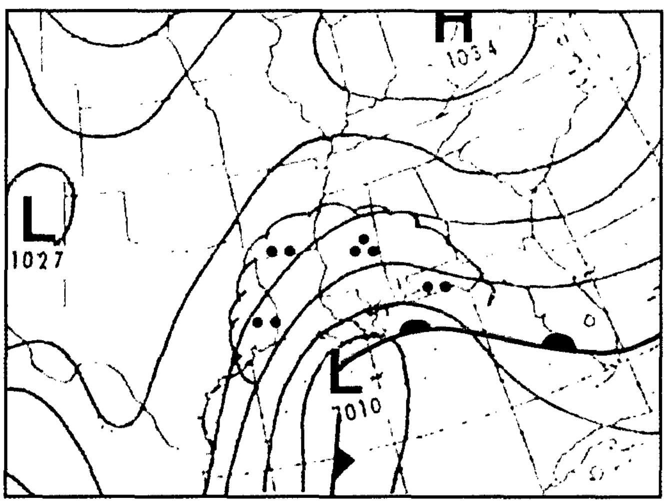

Figure 5-73. Surface, 1200Z/ 26 November 1980
West Gulf Low frontal wave has developed. Inverted trough axis over Mississippi and Alabama to Kentucky/Tennessee suggests surface low will track along this axis.

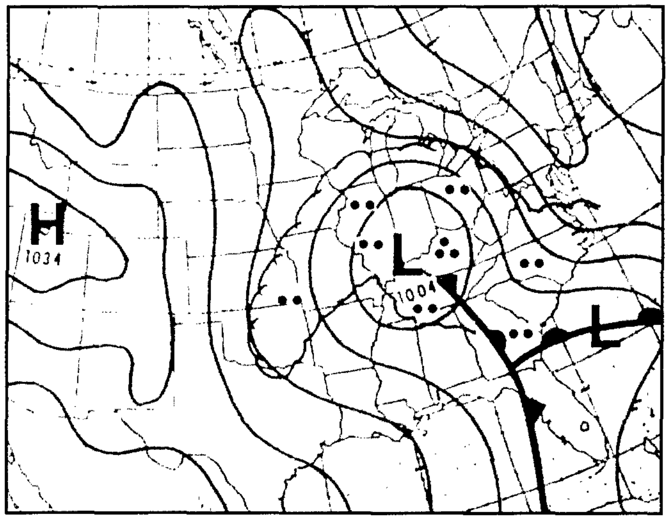

Figure 5-74. Surface, 1200Z/27 November 1980
The low pressure system has occluded. Precipitation is rain due to strong warm air advection.

In the example just shown, the vorticity center moved into the lower end of the comma rather than in the vicinity of the comma head. Typically, the southern end of a comma tail has lower cloud tops excluding convection. The lesson learned in this example is that each system is different, and the relationship between large comma and small vorticity comma systems will have many variations.

Another example of Gulf of Mexico polar front development is shown in Figures 5-75 and 5-76. In Figure 5-75, the short wave low shown in the vicinity of El Paso, Texas (ELP—indicated by the circle with cross hairs) moved from southern California 12 hours earlier. The low over Mexico should not be considered as the main low although it stacks with the 500 mb low. It is the frontal wave that developed in the Gulf shown east of southern Texas that will eventually become the main surface low (West Gulf Low). The low will deepen as the upper-level low "captures" the West Gulf Low shown in Figure 5-75.

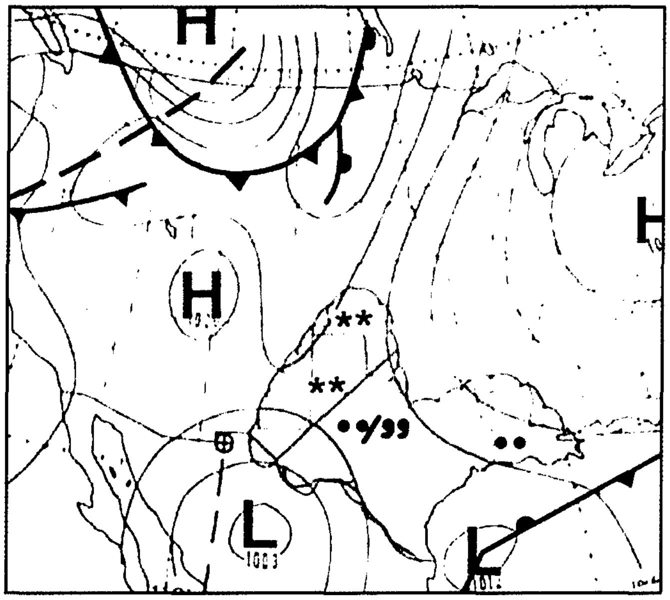

Figure 5-75. Surface, 0000Z/3 January 1973
Precipitation from the West Gulf Low extends to the southern Rockies. Increasing snowfall as short wave moves out of the southern Rockies.

In Figure 5-76 (24 hours later), the West Gulf Low moved rapidly northeastward to Illinois from the Gulf. The short wave and closed low recurved over the southern Great Plains, and the surface system responded likewise. The long arrows shown in Figure 5-76 depict the track of the storm. As the storm progressed northward, it caused heavy snow from the Texas Panhandle to the Great Lakes.

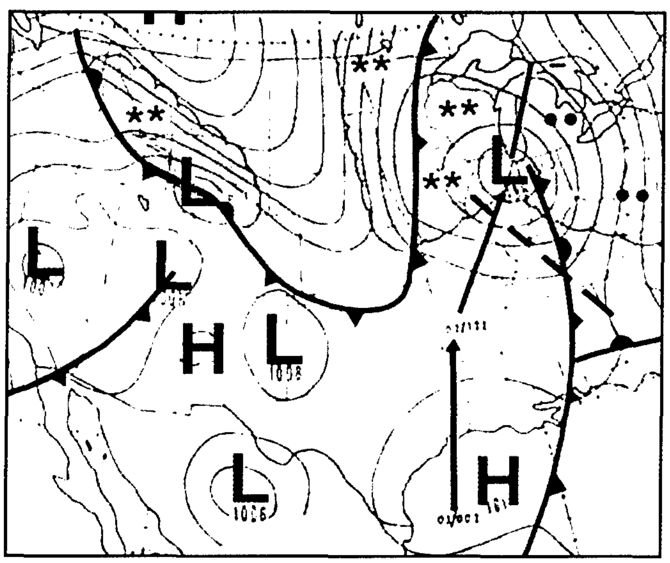

Figure 5-76. Surface, 0000Z/4 January 1973

The super storm that occurred on Saturday, 13 March 1993, began in the western Gulf of Mexico along a stationary polar front as shown in Figures 5-78. In Figure 5-77, the 500 mb analysis reveals several minor PVA systems moving through the long wave trough. In Figure 5-78, a prevailing high-pressure regime exists across the entire CONUS. The thickness pattern shows a trough over the Central Plains. The frontal low continued eastward and intensifies rapidly over the eastern Gulf of Mexico. It moved due north across the eastern CONUS dumping unbelievable amounts of snow from Alabama/Georgia northward to Maine (Figures 5-79 through 5-82).

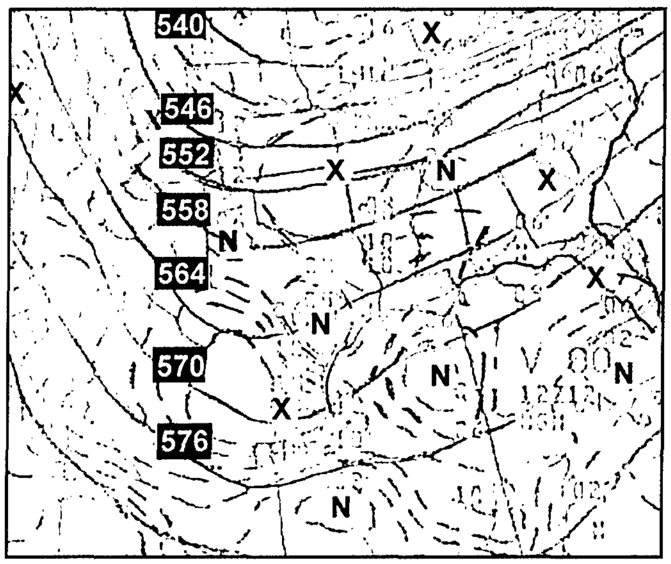

Figure 5-77. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/12 March 1993

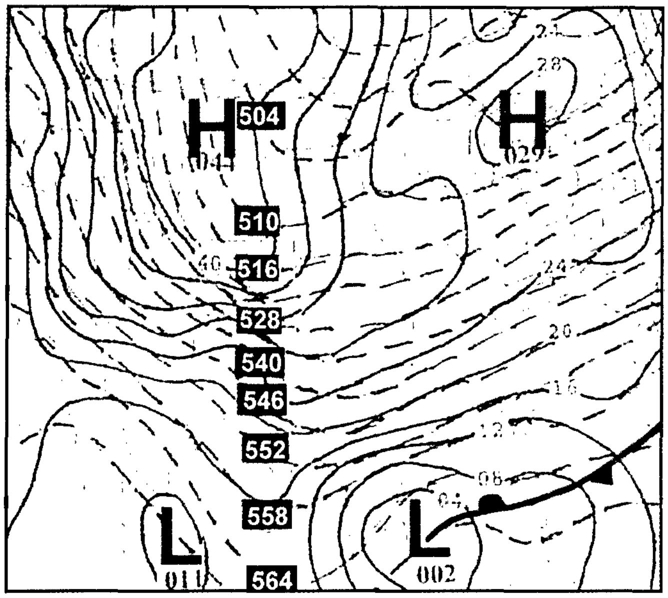

Figure 5-78. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/12 March 1993

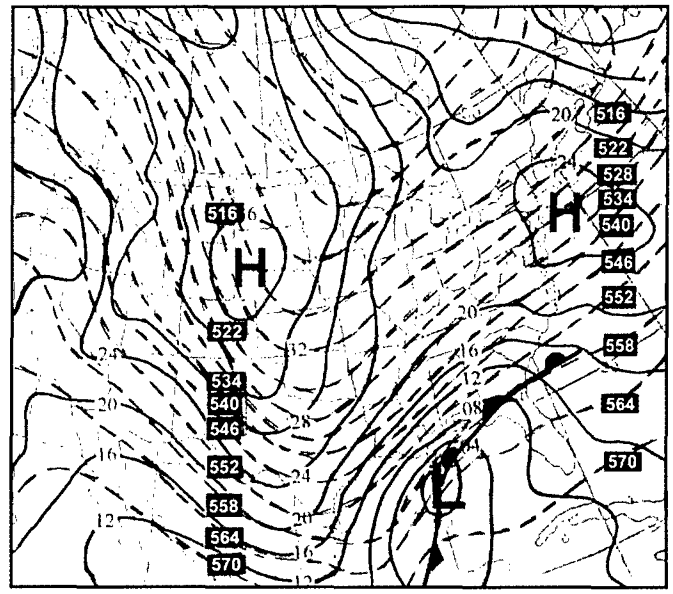

Figure 5-80. 12HR FCST PRES/1000-500 mb THKNS, 0000Z/13 March 1993

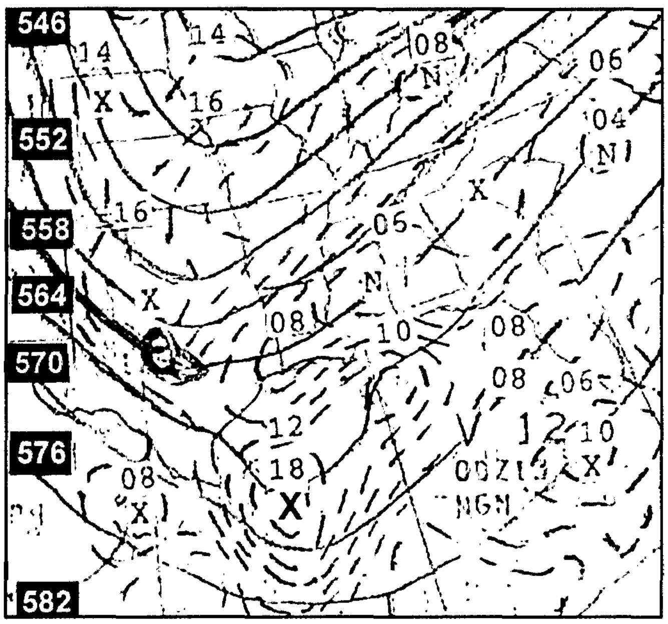

Figure 5-79. 12HR, 500 mb HEIGHTS/VORTICITY, 0000Z/13 March 1993

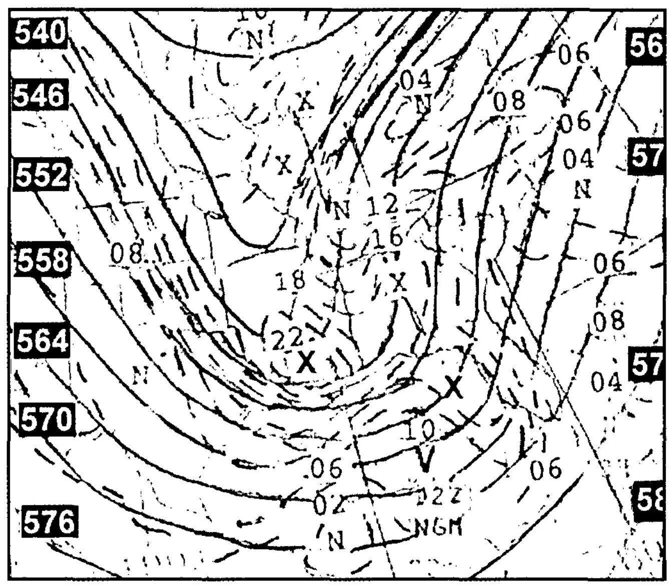

Figure 5-81. 24HR 500 mb HEIGHTS/VORTICITY, 1200Z/13 March 1993
Strong PVA at the base of the long wave trough.

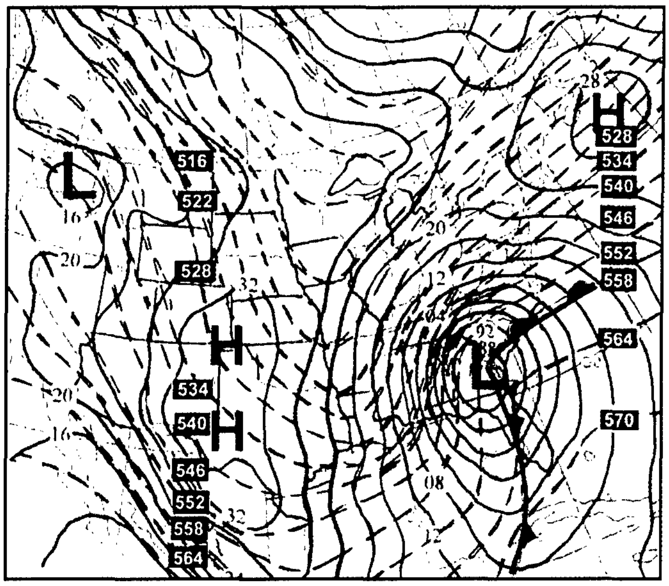

Figure 5-82. 24 HR MSL PRES/1000-500 mb THKNS, 1200Z/13 March 1993
Unbelievable snowfall amounts over 36" occurred over the Appalachians.

Southeastern CONUS Cyclogenesis

Digging short waves may undergo cyclogenesis within the middle troposphere over the southeastern region of the CONUS. Features such as a widening of the isothermal and contour gradients, cold troughs and a jet maximum will likely indicates cyclogenesis within the next 12-24 hours. These features were presented earlier in Chapters 3 and 4. An example is shown in Figures 5-83 through 5-86. In Figure 5-83, a short wave centered over the Great Plains is digging southeastward. Notice the wide contour and thermal gradients over Iowa (hatched box). A jet max of 60 knots is shown over Oklahoma, Arkansas and northern Texas. At the surface, Figure 5- 84, a prevailing cP high (Alberta High) regime is in place. Extensive precipitation extends from the Gulf to the Ohio Valley area as a result of overrunning and PVA associated with the upper system. A polar frontal low (East Gulf Low) has developed along the Louisiana coast that probably is connected to the developing upper low.

Development of Gulf Lows along stationary polar fronts occurs often. However, as a general rule, these lows will move east to northeast across the southeastern states. Some of these storms intensify rapidly once they moved into the Atlantic coastal areas. Normally, precipitation from these systems affects the southern and eastern CONUS as the disturbance lifts northward across the eastern seaboard.

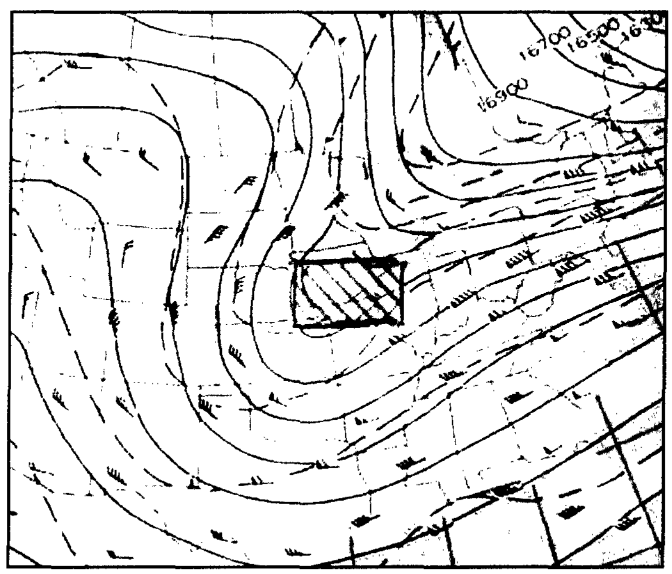

Figure 5-83. 500 mb, 1200Z/1 March 1980
Wide contour spacing suggest cyclogenesis.

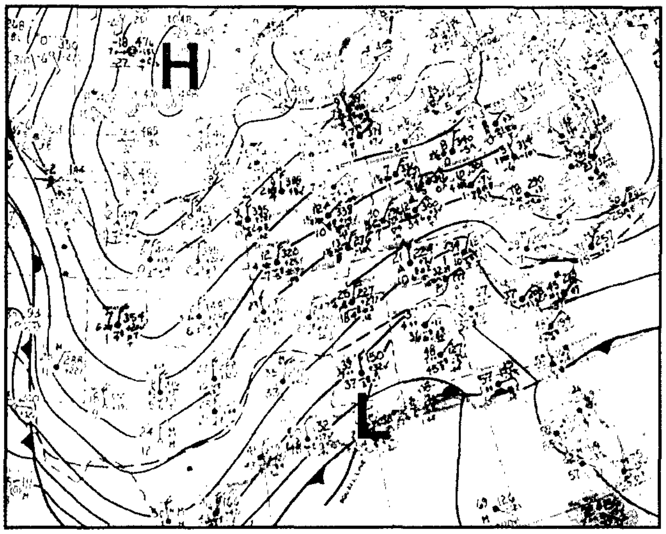

Figure 5-84. Surface, 1200Z/1 March 1980
Prevailing cP high. Frontal wave (East Gulf Low) has developed.

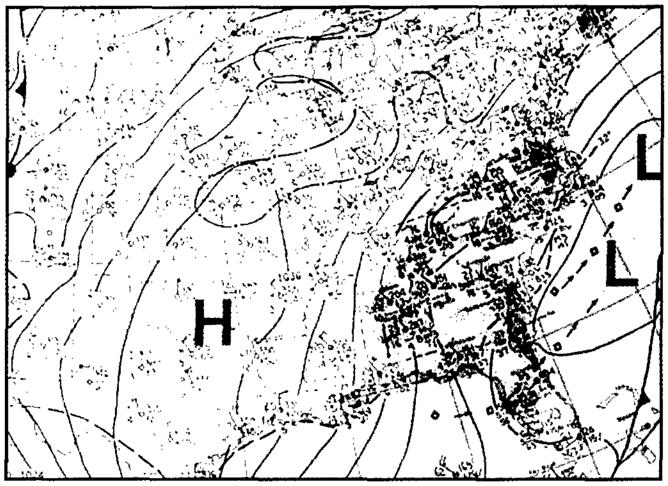

Figure 5-86. Surface, 1200Z/2 March 1980

In Figure 5-85 (24 hours later), a split-flow closed low appears within the 500 mb flow and is located to the southeast of the hatched area shown in Figure 5-83. At the surface, Figure 5-86, the East Gulf Low has moved across Florida and appears off the southeastern CONUS coast. Precipitation, mostly snow, continues behind the surface low, and the precipitation is associated with the upper system.

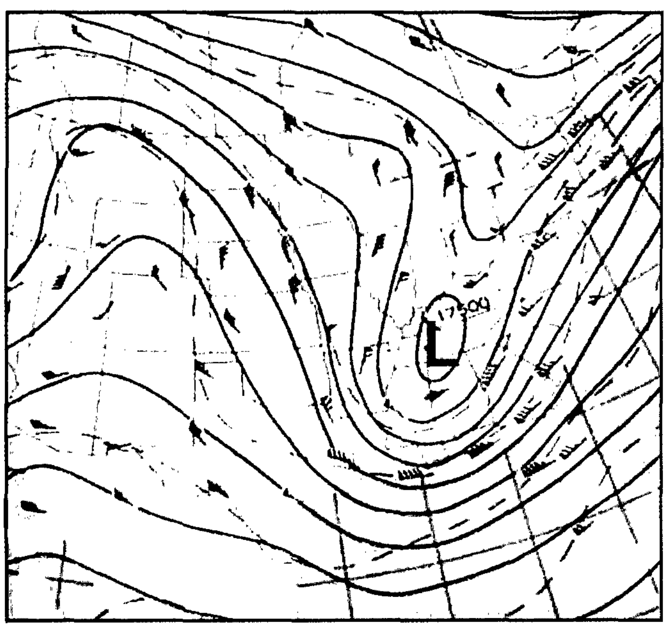

Figure 5-85. 500 mb, 1200Z/2 March 1980

Non-Convective Surface Wind Regimes (Notorious Wind Boxes)

Great Lakes and the Appalachian Mountains Boxes

The prevailing wind direction in the Great Lakes and the Appalachian Mountains boxes is west to northwest. Figure 5-87, depicts Great Lakes areas affected by strong cold air advection (CAA) winds. When a large-scale cyclonic circulation occurs over the eastern CONUS, it would be difficult to discern between these two wind events. Cold air advection winds would prevail within the circulation. The leg tracks shown in Figure 5-88 are various pressure differentials dependent upon wind directions (see AWS-TR-219 for further information). Figures 5-89 and 5-90 respectively show examples of a low-level and mid-level maximum wind charts. In both figures, the strongest winds are southerly along the East Coast.

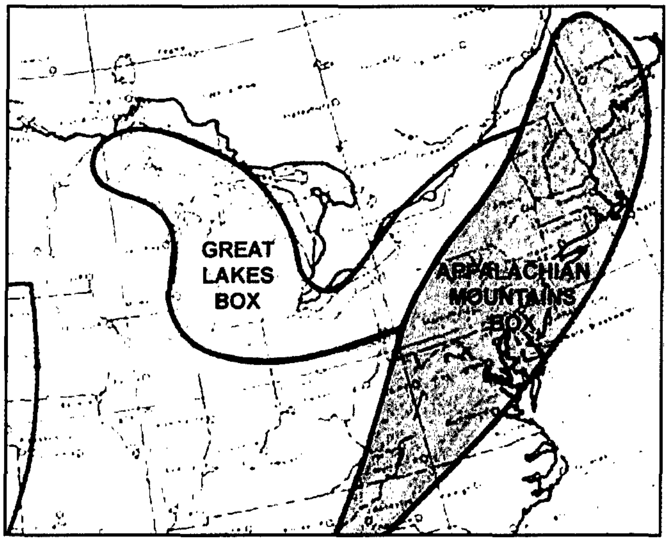

Figure 5-87. Great Lakes Box

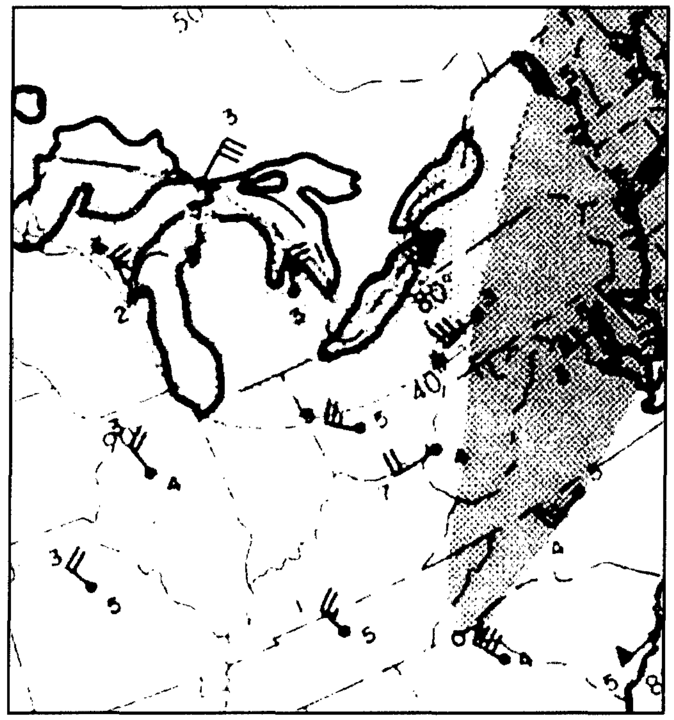

Figure 5-89. Great Lakes and Appalachian Boxes Low-Level Maximum Winds

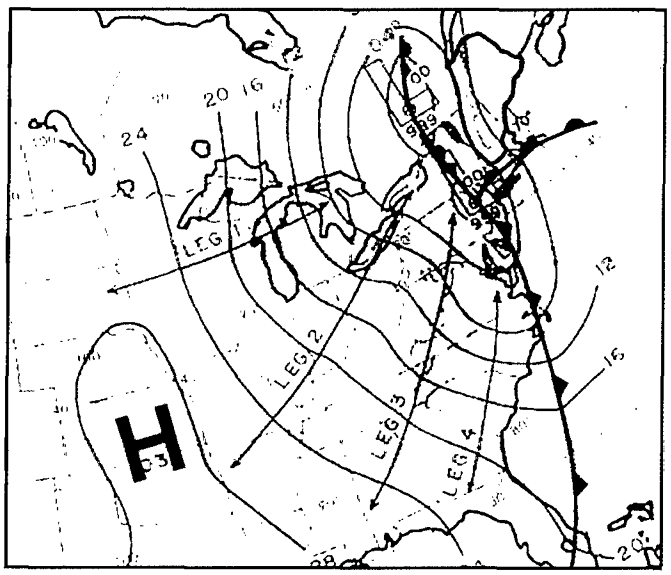

Figure 5-88. Great Lakes and Appalachian Boxes Surface Example

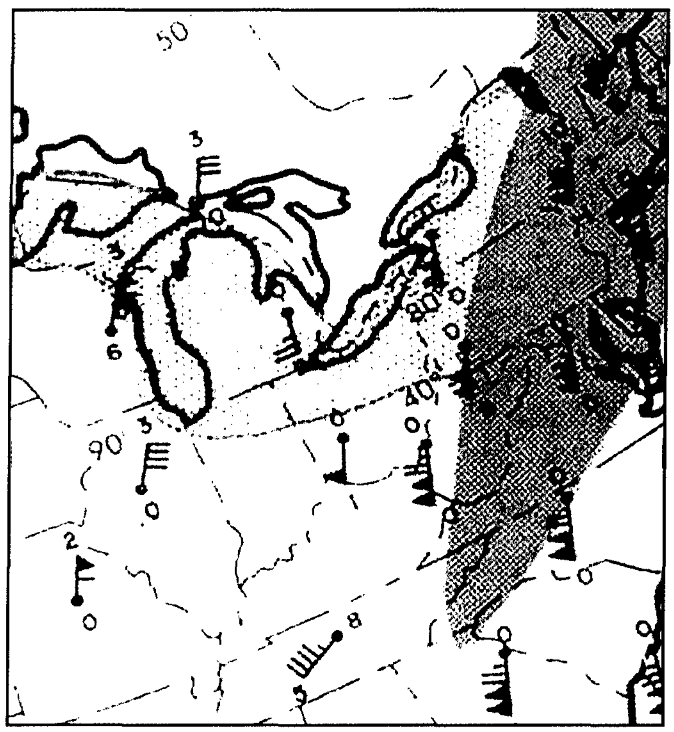

Figure 5-90. Great Lakes and Appalachian Boxes Mid-Level Maximum Winds

Appalachian Mountains Box

The Appalachian Mountains Box occurs most often when strong cold fronts move across the mountains from New England to northwestern Georgia. Forecasters should look for tight pressure gradients and strong pressure rise and fall couplets. Several scenarios for strong Appalachian Mountain wind events are documented, but the most common pattern is shown in Figures 5-91 and 5-92. Often, the first indicators of strong cold air advection winds are along the Appalachian ridgeline as the cold air rushes down the lee-side.

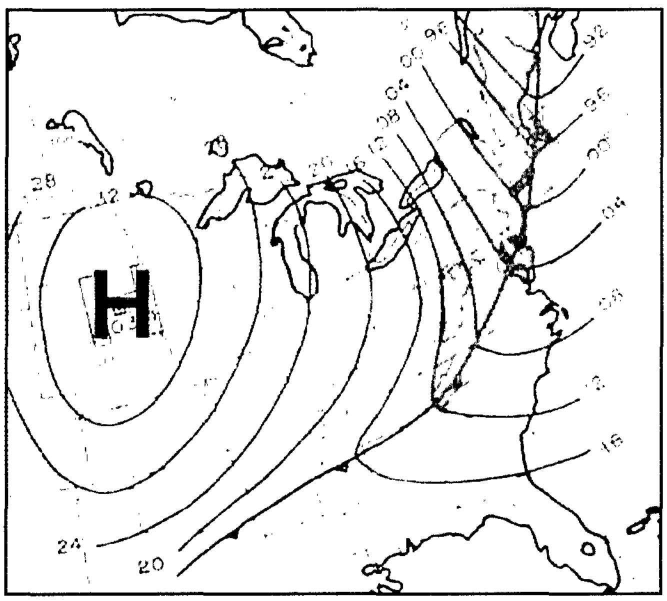

Figure 5-91. Appalachian Mountains Box Surface Example

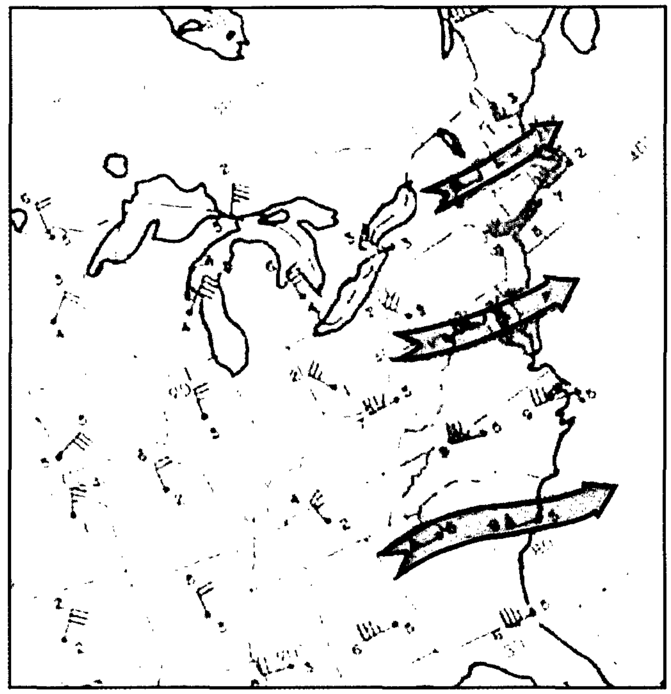

Figure 5-92. Appalachian Mountains Box Low-Level Winds Example

The wind areas shown in Figures 5-91 and 5-92 are where strong surface winds occur frequently over the eastern CONUS. A region where strong southerly winds occasionally occur is the Ohio Valley. This event is likely when a deepening low moves across the Great Lakes. The pressure gradients tighten ahead of the approaching cold front. Strong cold air winds may follow after cold FROPA. It is usually a short-lived event and the strongest winds are likely during the daytime.

Forecasters must remember that any area is capable of strong surface winds if the synoptic system is sufficiently strong. Strong polar or arctic highs pushing into the southern CONUS often produce strong winds in excess of 35 knots for a short period after cold FROPA.

Coastal Winds

Although not a notorious wind regime, occasionally strong easterly winds affect some coastal areas along the Atlantic Seaboard. This wind regime develops when a polar ridge is stationary over eastern Canada and/or the northeastern CONUS and a coastal low, located over the southeastern CONUS, is slowly moving northward. The pressure gradient tightens ahead of the low. These two features are shown in Figures 5-93. In this particular example, an upper low was associated with the surface system (Figure 5-94).

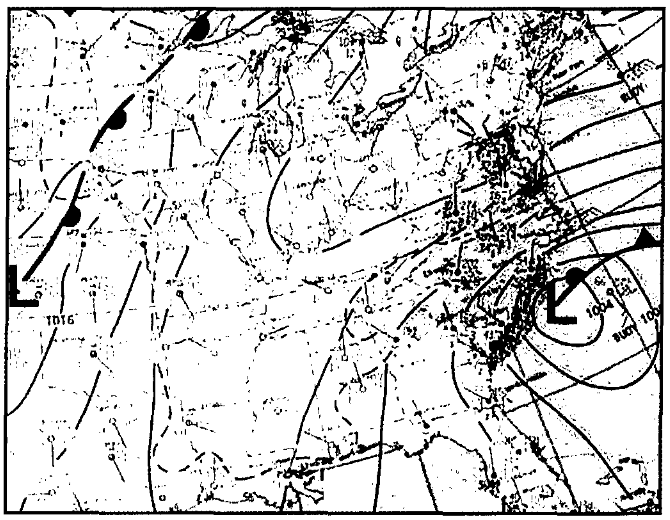

Figure 5-93. Surface, 1200Z/28 December 1980

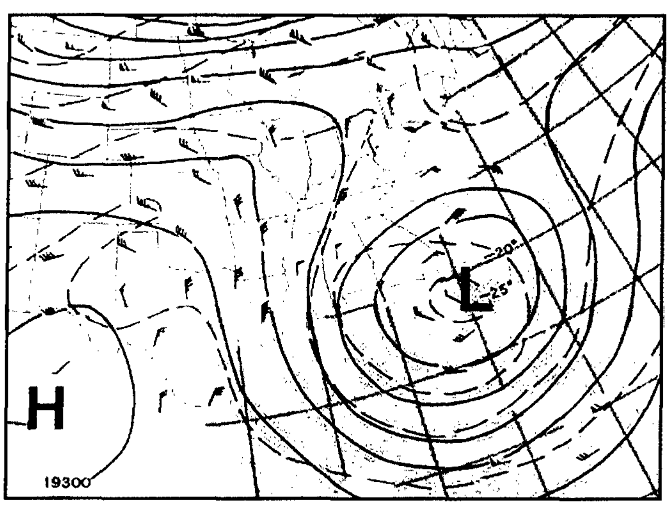

Figure 5-94. 500 mb, 1200Z/28 December 1980

Lake Effect Snows in the Great Lakes

Frequent periods of low ceilings, snow showers and gusty northwest winds affect Great Lakes locations and eastward to Pennsylvania and New York when strong lows move into New England and southeastern Canada (Figures 5-95). Western areas of New York and Pennsylvania affected by the "Great Lake Effect" received heavy snowfall when slow-moving, deep occluded lows are located over the Hudson Bay – Labrador region. In Figure 5-96, cloud streets parallel to the low-level wind flow can be seen from the eastern shores of Lakes Michigan, Ontario and Erie. This pattern continues until a low-level ridge moves in from the west and shifts winds to a southerly component. The Great Lakes effect snows may subside when the ice cover increases over some sections of the Great Lakes. Locations affected by this localized heavy snowfall regime have many good rules that use temperatures differentials, low-level wind direction and strength between land and water surfaces.

These rules help to predict convergent cloud lines over the lakes and their movements and where to expect heavy snow to fall. Considerable discussion and illustrations are included due to the frequency of occurrence of this winter regime.

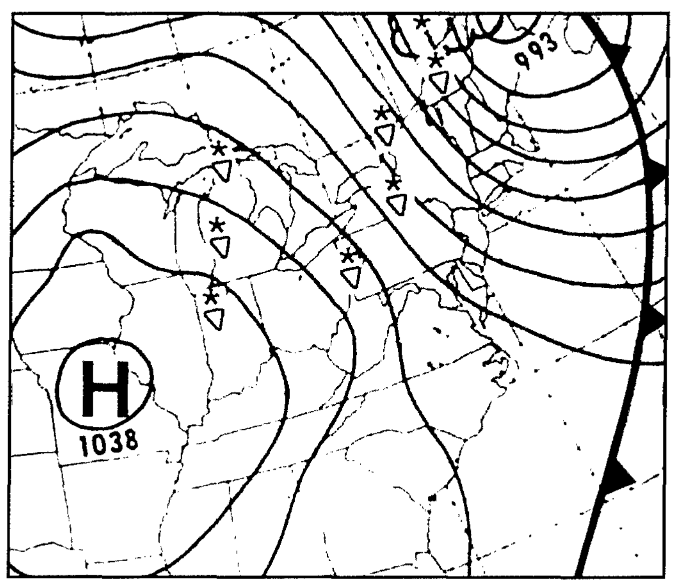

Figure 5-95. Surface, 1800Z/8 December 1979
Ridging is approaching from the west.

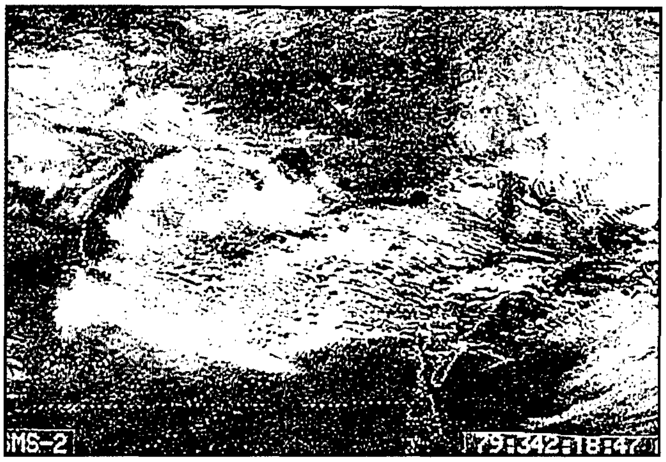

Figure 5-96. Synchronous Meteorological Satellite (SMS-2) VIS, 1847Z/8 December 1979
Northwesterly cold air continues across the Great Lakes.

Several lake effect events occurred in late November and early December 2000 and are presented at this time. The first event occurred on 22 November 2000. A long wave trough was established over the eastern CONUS. A small, vigorous Canadian short wave dropped rapidly southeastward into the Great Lakes region as shown in the ETA 500 mb analyses (Figure 5-97). Lake effect activity was already occurring; the short waves added to the strength of lake effect as it moved eastward. Figure 5-98 depicts the ETA surface analysis.

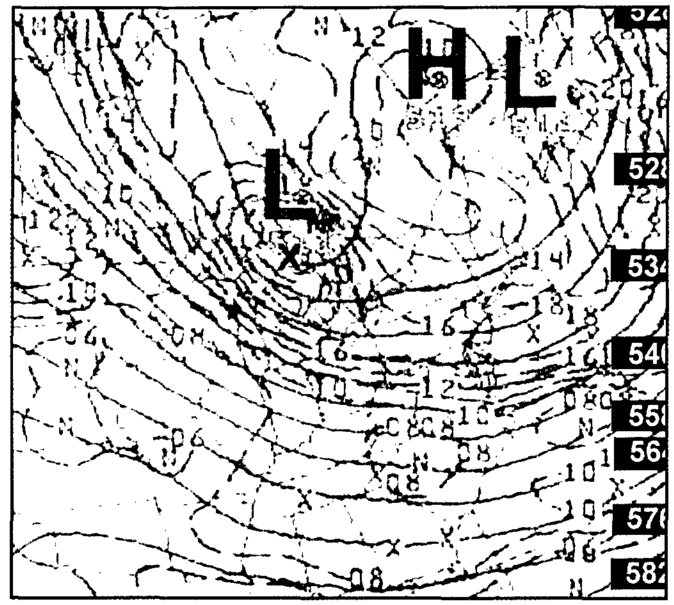

Figure 5-97. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/22 November 2000
Strong short wave/PVA over the Great Lakes.

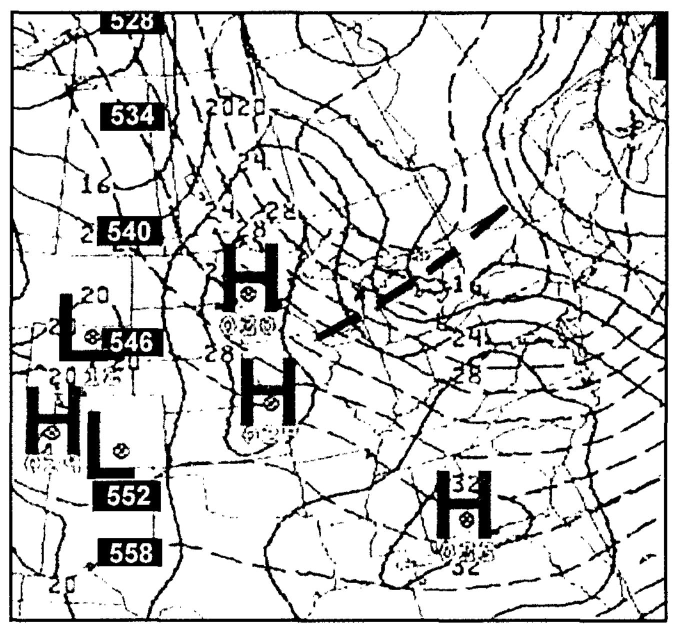

Figure 5-98. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/22 November 2000
Surface trough over the Great Lakes is associated with the short wave.

Figures 5-99 through 5-101 show the cloud banding and lake effect snows that occurred. Buffalo, New York (KBUF) received heavy snowfall from this event. Figure 5-99 (GOES-E VIS) indicates the large areal expanse of this storm system. Figures 5-100 and 5-101 (from the NOAA OSEI Archives) have a more regional focus.

Figure 5-99. GOES-E VIS, 1702Z/ 22 November 2000

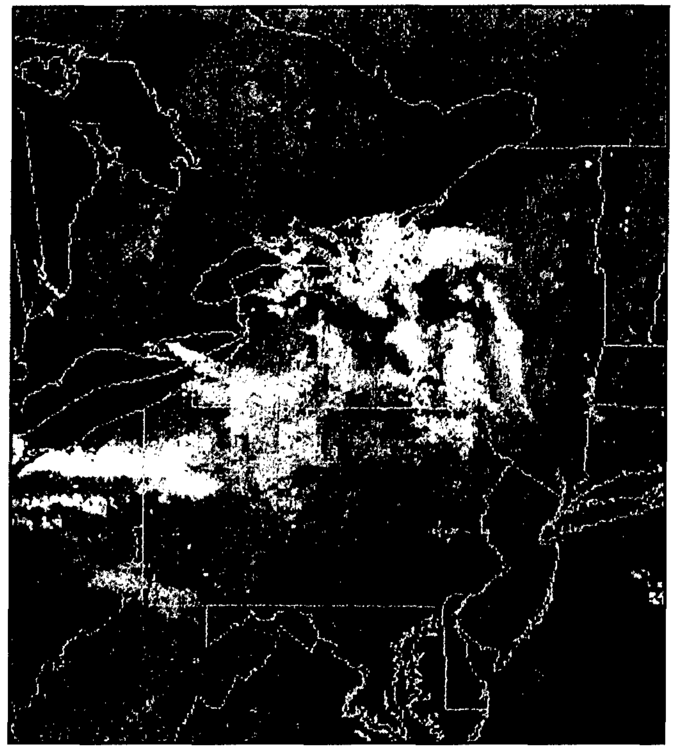

Figure 5-100. Eastern Great Lakes Satellite/ Radar Composite Image, 2159Z/ 22 November 2000

Lake effect snow bands shown as bright white. Grays show clouds.

Figure 5-101. GOES-E Colorized VIS, 1645Z/22 November 2000

Another similar event occurred two weeks later on 5 December 2000. An upper trough was located over the eastern CONUS. A Canadian short wave moved across the Great Lakes as depicted in the NGM 500 mb analysis (Figure 5-102a). The surface features shown in Figure 5-102b are similar to the 22 November event (Figure 5-98) where a strong cP air flowed across the Great Lakes.

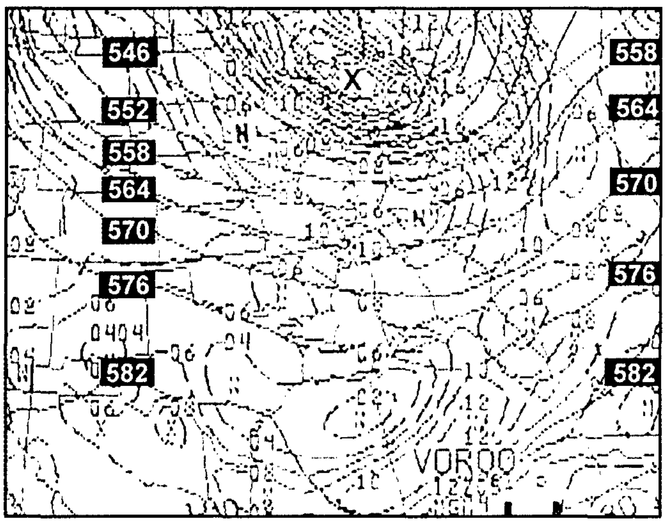

Figure 5-102a. 00HR 500 mb HEIGHTS/ VORTICITY, 1200Z/5 December 2000

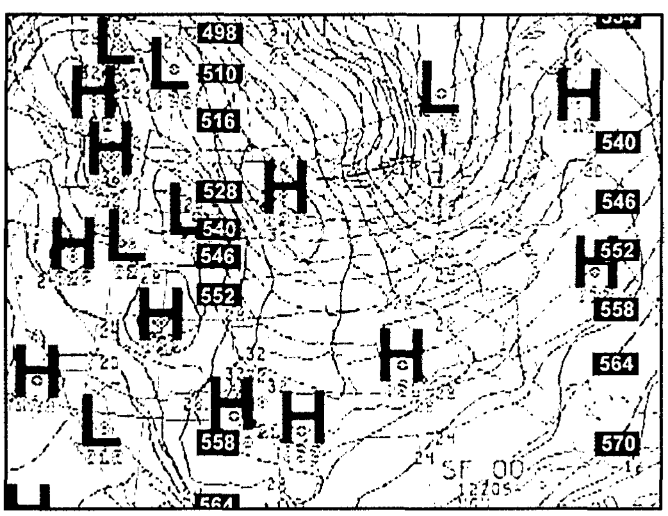

Figure 5-102b. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/5 December 2000

Clouds formed over the central and eastern areas of the Great Lakes. Discerning between snow on land surfaces and lake effect clouds would be difficult on still pictures (use radar and satellite animation). Figures 5-103 through 5-105 show excellent radar and satellite images of this lake effect event. Clouds can be seen over the central and eastern areas of Lake Michigan and over Lakes Erie and Ontario and south of Lake Superior in Figure 5-103. Although absent in Figure 5-103, snowfall from previous synoptic-scale storms will cover large areas of the northern Great Plains and eastward to the Atlantic Coast. In these cases, Great Lakes effect snows would be masked. A simple rule in satellite interpretation: if it doesn't move then it is snow.

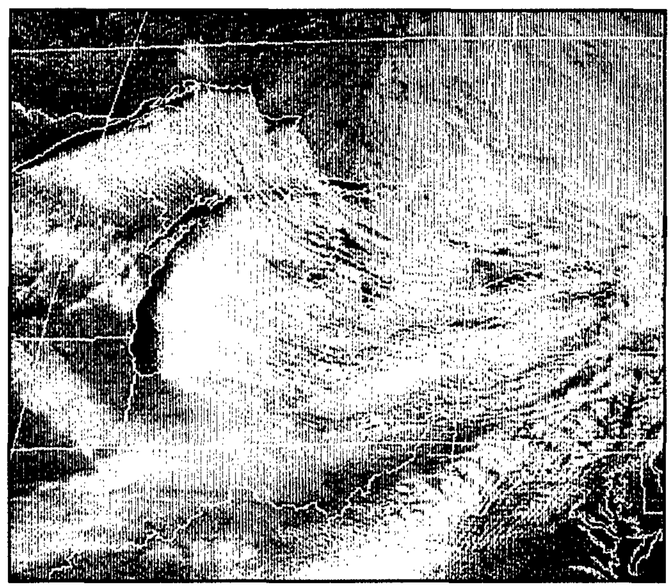

Figure 5-103. GOES-E VIS, 1855Z/ 5 December 2000

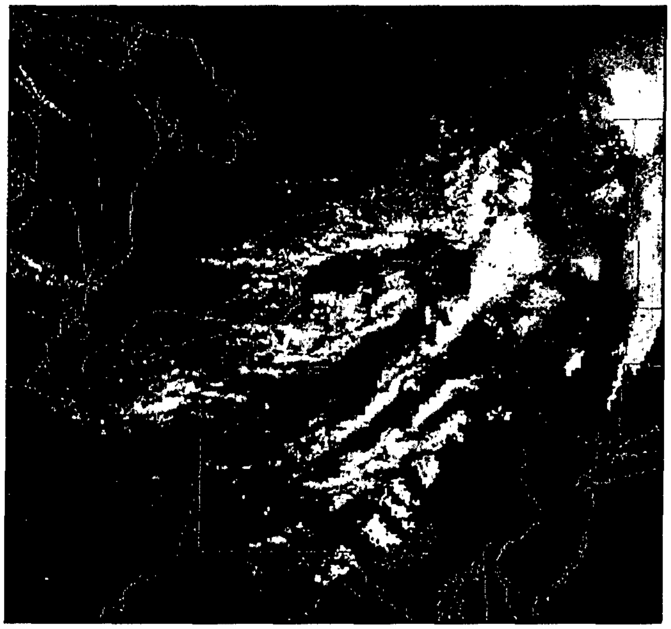

Figure 5-104. Eastern Great Lakes Satellite/ Radar Composite Image, 1909Z/ 5 December 2000

Lake effect snow bands shown as bright white. Grays show clouds. Pink areas indicate sleet, mixed rain and snow, and/or freezing precipitation. Green areas show rain.

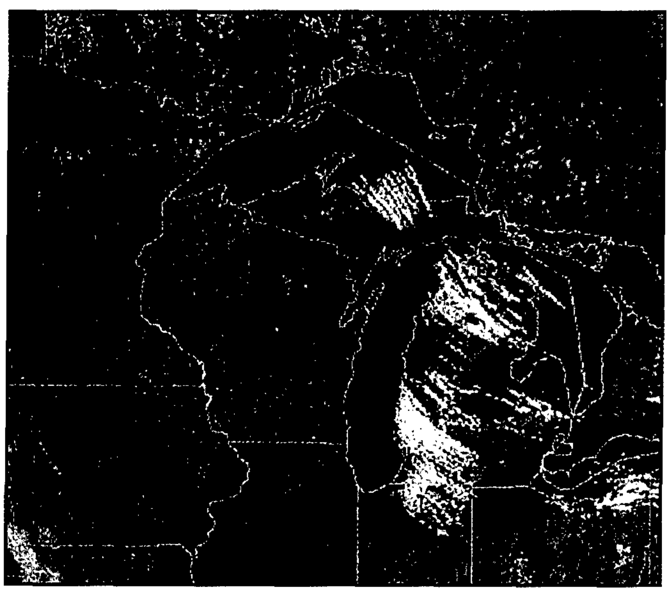

Figure 5-105. Western Great Lakes Satellite/ Radar Composite Image, 1906Z/ 5 December 2000

Lake effect snow bands shown as bright white. Grays show clouds.

WSR-88D Doppler radars, located within the range of areas affected by lake effect snow, are excellent forecast tools for onset and movement of these persistent snow bands. These bands often remain nearly stationary and dumped large amounts of snow over a given area. The following Doppler radar illustrations (Figures 5-106 through 5-108) is presented to show snow bands that form along the eastern side and adjacent land areas of Lakes Michigan, Erie and Ontario.

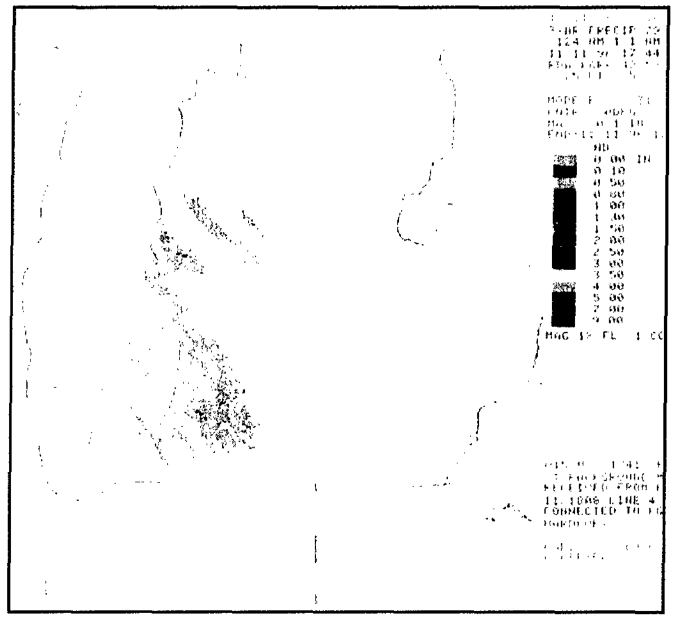

Figure 5-106. Grand Rapids, Michigan (KGRR) 3-Hour Precipitation, 1744Z/ 11 November 1996

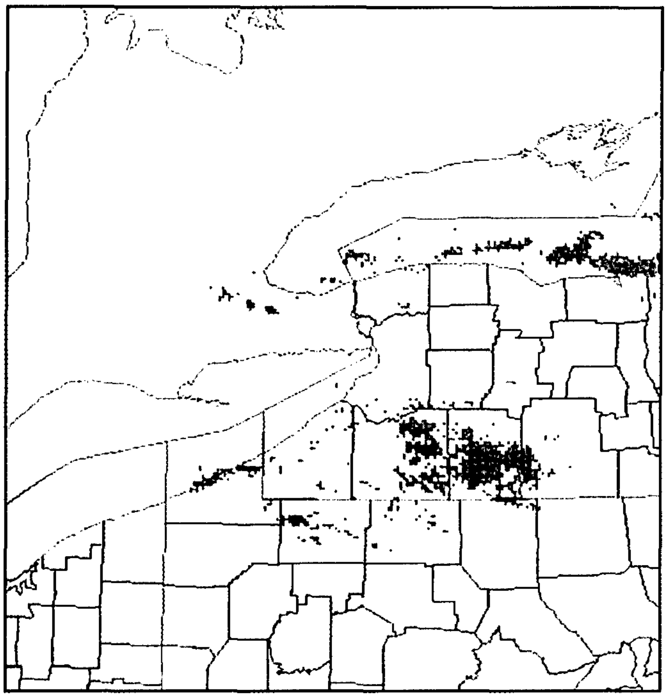

Figure 5-107. Buffalo, New York (KBUF) 3-Hour Precipitation, 1805Z/11 November 1996

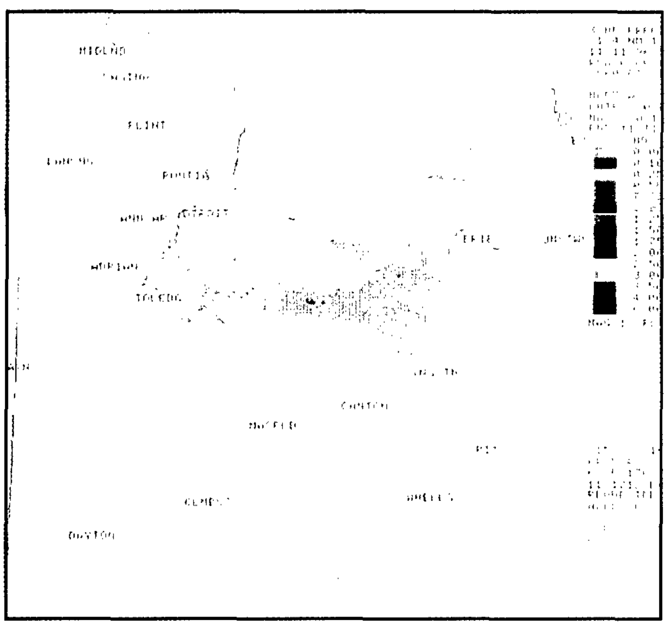

Figure 5-108. Cleveland, Ohio (KCLE) 3-Hour Precipitation, 1700Z/11 November 1996

Great Lakes Lake Effect Snow Patterns

The following four illustrations are empirical models of areas affected by lake effect snow. Simply, it is a matter of relating low-level wind direction across the lakes generally under a cyclonic circulation. The hatched areas shown in all figures depict the areas most likely to be affected by the strongest lake effect and heavy snowfall. The wider hatched area shown in Figure 5-110 over the Appalachian Region is added because moist lake winds and cloudiness will produce heavy snow over the mountains as far south over West Virginia, western Virginia and North Carolina under a strong northerly flow (also affects locations south of Lake Michigan).

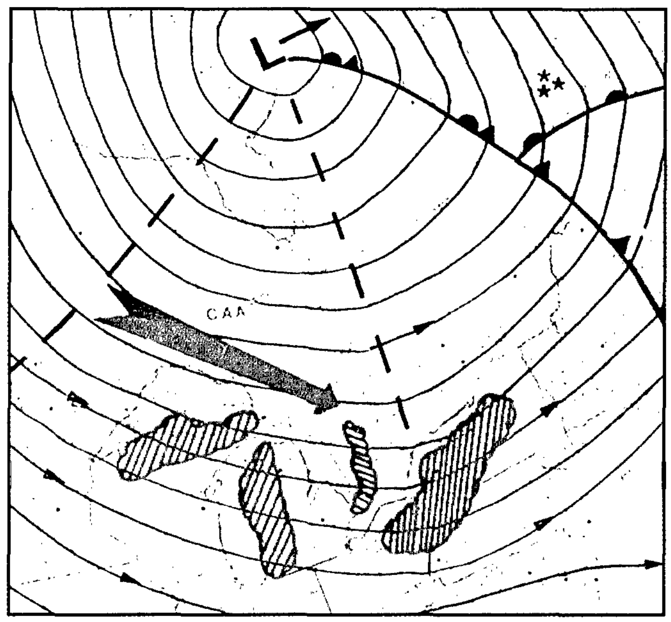

Figure 5-109. Strong Northwesterly Flow Lake Effect Regime

This is the most common lake effect snow situation.

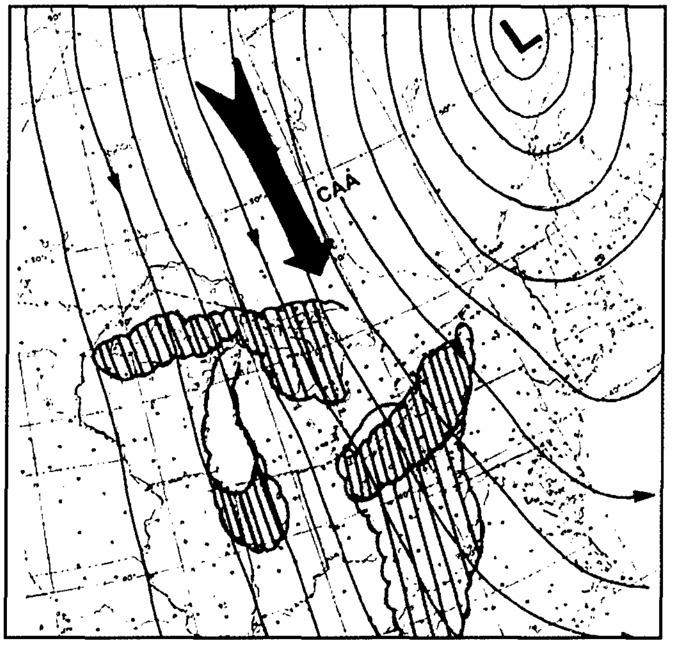

Figure 5-110. Strong Northerly Flow Lake Effect Regime

In Figure 5-111, a cold cP high pressure system would be in place rather than a low as shown in all the other figures. Lake effect snows are likely over locations on the windward side of the lakes due to a low-level easterly flow.

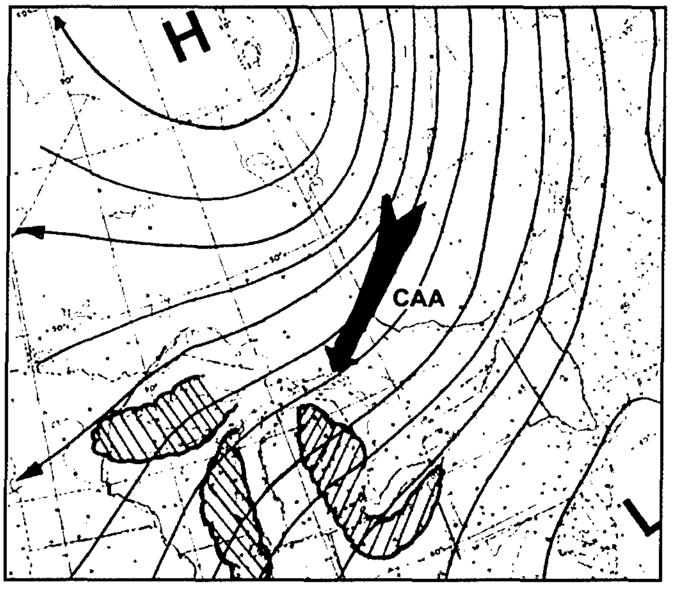

Figure 5-111. Strong Northeast Flow Lake Effect Regime

Duluth, Minnesota and Chicago, Illinois would receive significant lake snow due to the easterly funneling effect.

In Figure 5-112, there would be an absence of lake effect snow over Lakes Erie and Ontario because the low-level winds are parallel to the lakes. This would limit cP air from flowing across the lakes. Due to the long fetch of lake moisture within southwest flow, the Buffalo (KBUF) and Watertown (KART) areas in New York located upstream and where the land narrows (a funneling effect) would received considerable lake effect snow.

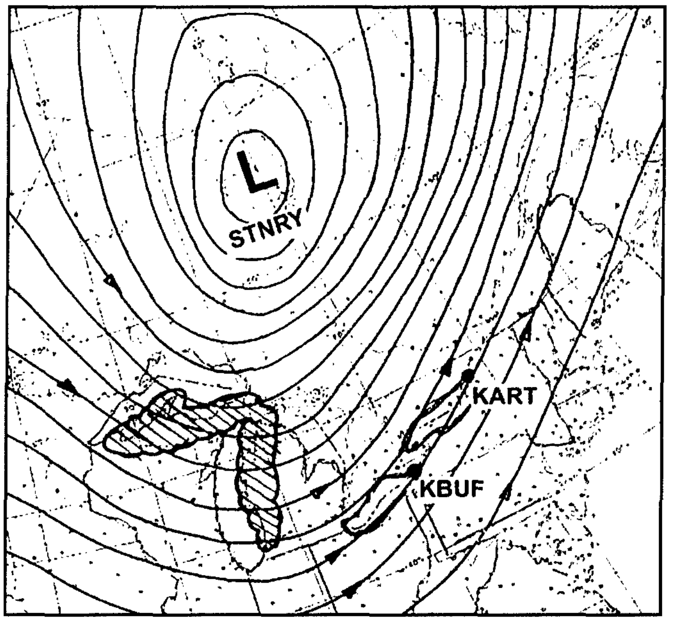

Figure 5-112. Stationary Low Widespread Lake Effect Regime

Deep cold-core low stationary over Hudson Bay.

The following are tidbits of information regarding lake effect snow events:

- Begins when a series of cP cold fronts/troughs track southeastward across the Great Lakes resulting in a strong temperature discontinuity between the warmer waters of the lakes and the advancing polar air mass.
- Cloud lines develop parallel to the low-level wind flow due to convergence in the wind fields over the central and eastern regions of the Great Lakes. Snow showers/squalls will develop over the rising terrain, which provide the orographic lift to produce precipitation.
- Lake effect clouds/snows are generally a low-level phenomenon and can produce unbelievable snowfall amounts in a short period of time.
- Often, the cloud lines will remain stationary over the same locations dumping very heavy snow while areas just a few miles away would not received any accumulating snowfall.
- The western New York, northwestern Pennsylvania, and northeastern Ohio areas that lie adjacent to Lakes Erie and Ontario receive the greatest amounts of snow.
- A persistent large-scale cyclonic flow across the Great Lakes will continue lake effect for several days. Note: Usually a stationary cold-core low is located over the northeastern regions of Canada.
- Lake effect heavy snowfall decreases significantly away from the moisture sources although clouds and light snow showers may continue over the drier land mass.
- Fast-moving Canadian short waves moving southeastward across the Great Lakes may blanket drier land areas with snowfall in conjunction with on-going lake effect snows. Often, a north-south oriented trough is the surface reflection of the short wave.
- Very strong westerly lake effect moisture can reach as far eastward as the mountains of central New York and Pennsylvania. Additionally, a strong northerly lake effect moisture fetch can produce heavy mountain snows in the Appalachian Mountains of West Virginia, western Virginia and North Carolina, and eastern Kentucky and Tennessee.
- Lake effect snows shut down when low-level ridging and/or warm air advection moves across the moisture source.
- Areas of the Great Lakes may freeze over by mid-winter reducing the discontinuities between lake and ground temperatures. Lake effect snow/cloud cover will decrease significantly where polar air moves over ice-covered lakes.

Freezing Precipitation

The following freezing precipitation regimes have been extracted from AFWA/TN-98/001, *Freezing Precipitation.*

Northeastern CONUS Blocking Highs

Typically, most storm systems approaching the eastern CONUS lift northeastward into the New England region in response to upper trough deepening. There are infrequent occurrences when Great Plains storm systems (Colorado Lows, Northern Rocky Mountain Lows, Zonal Alberta Lows, etc.) will not move northeastward, but move easterly. Generally, a stationary cP high is located to the north of New England across the eastern Canada-Labrador region that prevents system movement to the northeast. Easterly, moist Atlantic air feeds into the storm system (along with Gulf moisture). A long period of freezing rain within a narrow band over the same general area is likely due to little or no northward lift as shown in Figure 5-113.

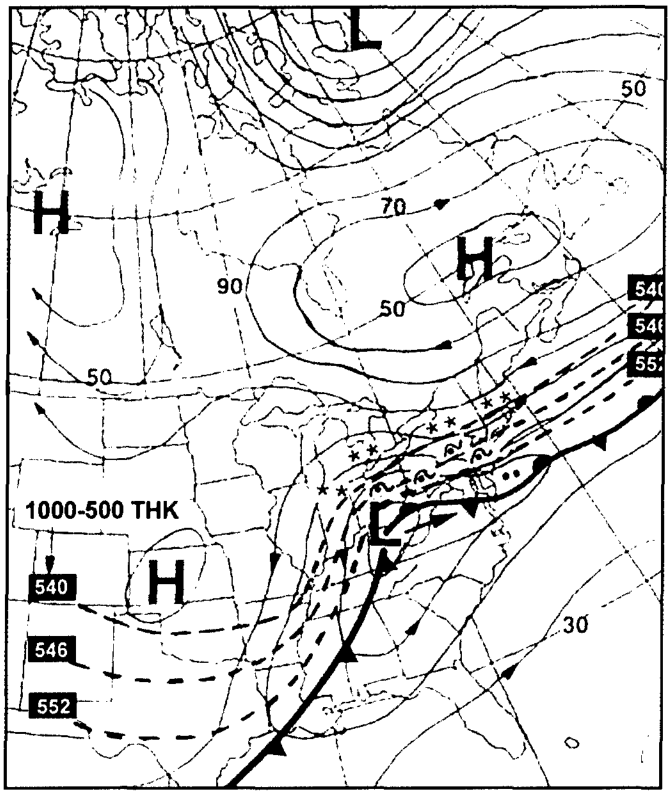

Figure 5-113. Northeastern CONUS Freezing Precipitation Situation

The model shows a situation where a Great Plains storm system (Colorado Low) moves eastward instead of northeastward. 1000-500 mb thickness isopleths are shown as dashed lines.

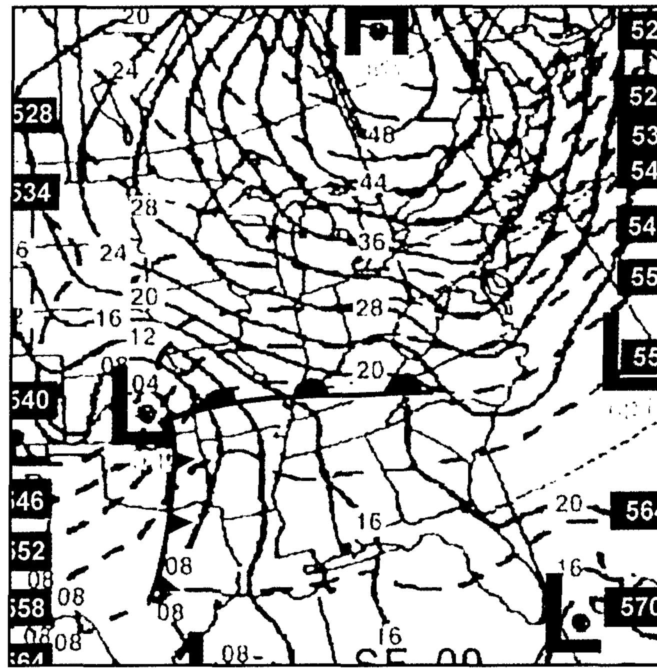

Figure 5-114. 00HR MSL PRES/1000-500 THKNS, 0000Z/27 January 1991

Ohio Valley/Great Lakes Warm Frontal

Figures 5-114 and 5-115 illustrate a typical warm-frontal freezing rain event over the northern Ohio Valley and Great Lakes region. The polar high recedes and warm moist overruns the shallow polar air ahead of a Great Plains storm. Significant ice storm often occurred with this regime. In Figure 5-115, all freezing rain has occurred between the 534 and 552 thickness ribbon.

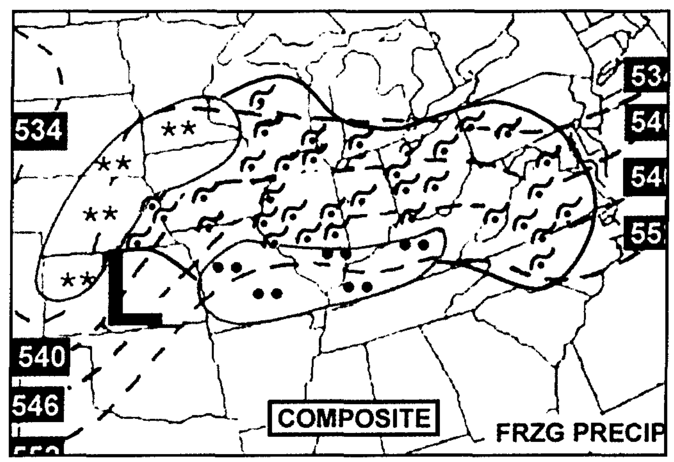

Figure 5-115. 1000-500 mb Thickness/Freezing Precipitation Composite, 0000Z/ 27 January 1991

Appalachian Cold Air Damming (CAD)

Occasionally during the winter months, a slow-moving cP high-pressure system located over Maine and northward into the Newfoundland/Labrador region will extend an elongated, shallow ridge southward across New England to the southern Appalachians. The ridge (or cold wedge) is usually along and east of the mountains and is shown in Figure 5-116. A strong low-level inversion and an easterly moist Atlantic flow produces upslope stratus along with fog; this pattern can persist for several days until strong warm air advection erodes the shallow ridge. A rain area associated with an approaching disturbance will overrun the shallow air mass and produce freezing rain for a few hours. A stationary front is usually along the Appalachian Mountain region as illustrated in Figure 5-116.

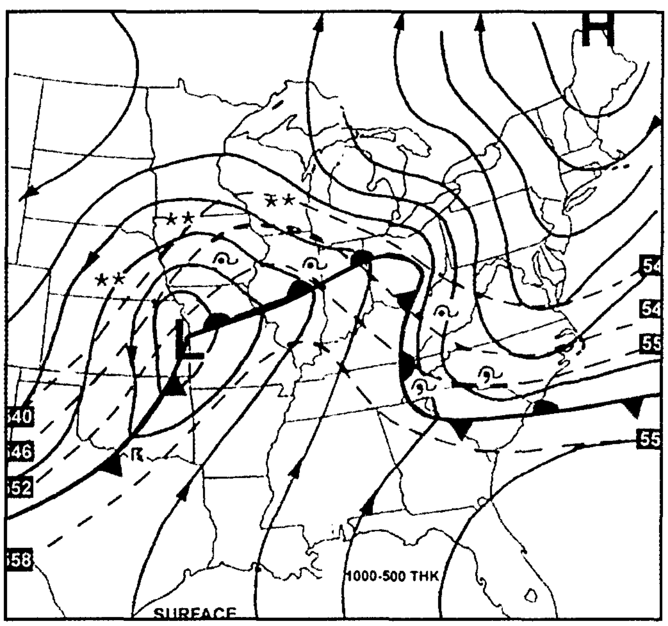

Figure 5-116. Appalachian Cold Air Damming (CAD) Pattern

An approaching storm and its warm air advection will eventually destroy the shallow cold wedge. The Appalachian front will undergo frontolysis and a new frontal boundary will appear further north where the better temperature and moisture discontinuities exist as shown in Figure 5-117.

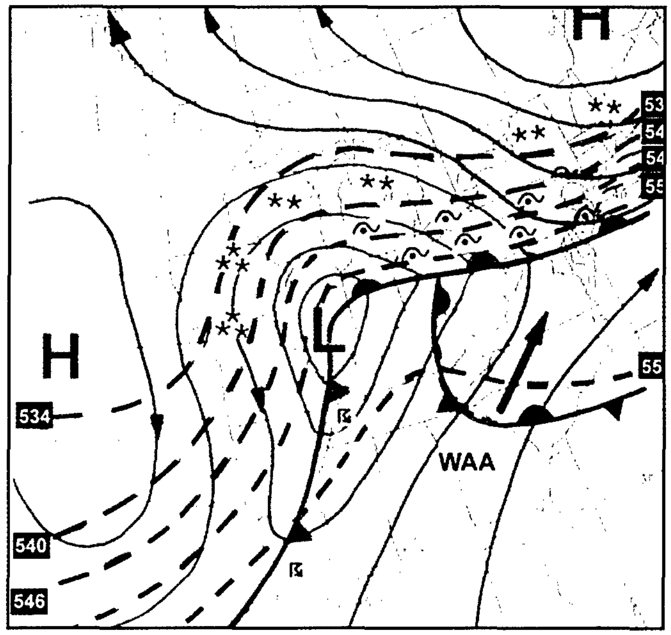

Figure 5-117. Appalachian Cold Air Damming (CAD) Progression

The stationary front "washing out," and the boundary is reestablishing itself farther north.

Southeastern CONUS Frontal

Frontal systems sometimes become stationary either along the coast or offshore. An upper-level trough deepening over the central CONUS slows these East Coast systems down. Rain associated with the upper trough continues behind the cold front and eventually changes to a freezing condition as low-level cold air moves eastward (Figures 5-118 and 5-119).

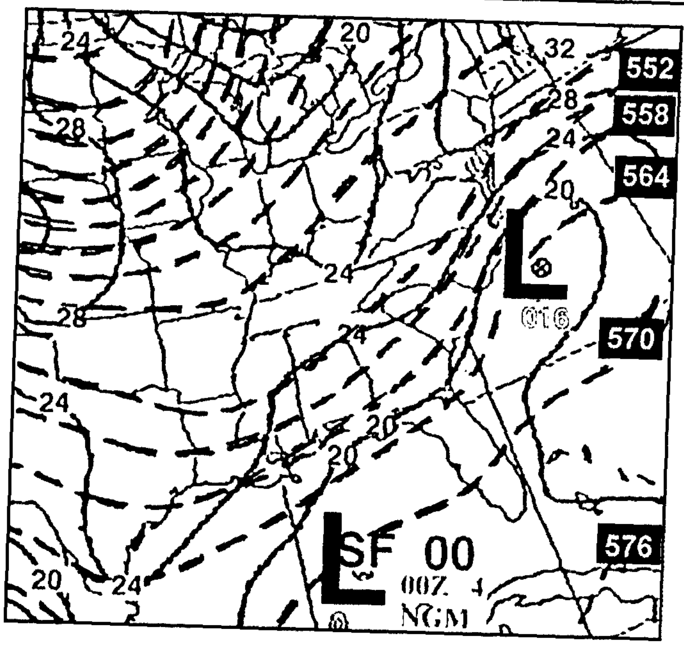

Figure 5-118. 00HR MSL PRES/1000-500 mb THKNS, 0000Z/4 January 1988

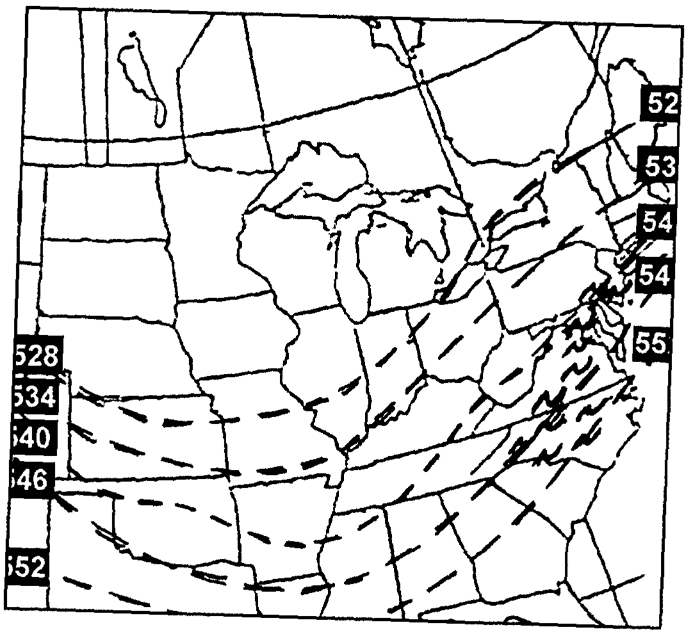

Figure 5-119. 1000-500 mb Thickness/Freezing Precipitation Composite, 0000Z/4 January 1988

Nearly all-freezing rain events affecting the southeastern CONUS are associated with prevailing high-pressure systems. Temperatures usually warm up to 32° F on the return flow of a receding high pressure system. Figure 5-120 depicts a favorable synoptic pattern for extensive freezing precipitation across the southeastern CONUS (prevailing high). The model shown here represents a typical setup for Gulf of Mexico frontal cyclogenesis (East Gulf Low) and the accompanying extensive overrunning precipitation. The surface pattern shown in Figure 5-120 may remain stationary for some time until a low-latitude impulse from the southern Rockies initiates frontal cyclogenesis in the Gulf. This stationary event would be classified as neutral advection at the surface.

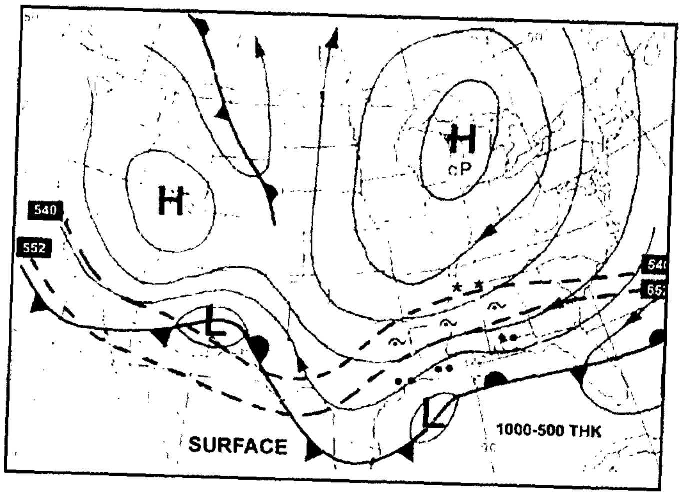

Figure 5-120. Southeastern CONUS Freezing Precipitation Situation - Setup

This is a favorable synoptic pattern for extensive freezing precipitation across the southern and southeastern CONUS. The primary low for development will be the East Gulf Low—not the South Pacific Low over southern Arizona and New Mexico.

Once a frontal low develops in the Gulf of Mexico with favorable upper-level support, the typical storm (East Gulf Low) moves eastward for a while then lifts northeastward due to upper-trough deepening (see example presented earlier in Figures 5-77 through 5-82). The low often moves across northern Florida as shown in Figure 5-121. The system continues to deepen as it moves into the Atlantic. Discontinuities between the colder land mass and the warmer Gulf Stream and the associated upper-level support enhances intensification or so-called "Cape Hatteras bombing." The thickness and temperature fields begin to show ridging as warm air feeds into the storm. These Gulf frontal lows produce extensive areas of precipitation back into the cold air as overrunning increases. The typical transition from rain, freezing rain and ice pellets to snow can be followed by eastern CONUS forecasters upstream as the deepening Hatteras Low moves northeastward (Figure 5-122). Ice storms (sometimes severe) occur east of the Appalachian Mountains from Georgia to New England as shown in the model patterns (Figures 5-121 and 5-122). A stationary cP high, usually located over the Great Lakes, provides cold air that advects into the system. Thunderstorms, sometimes severe, develop south of the frontal wave across the Florida peninsula.

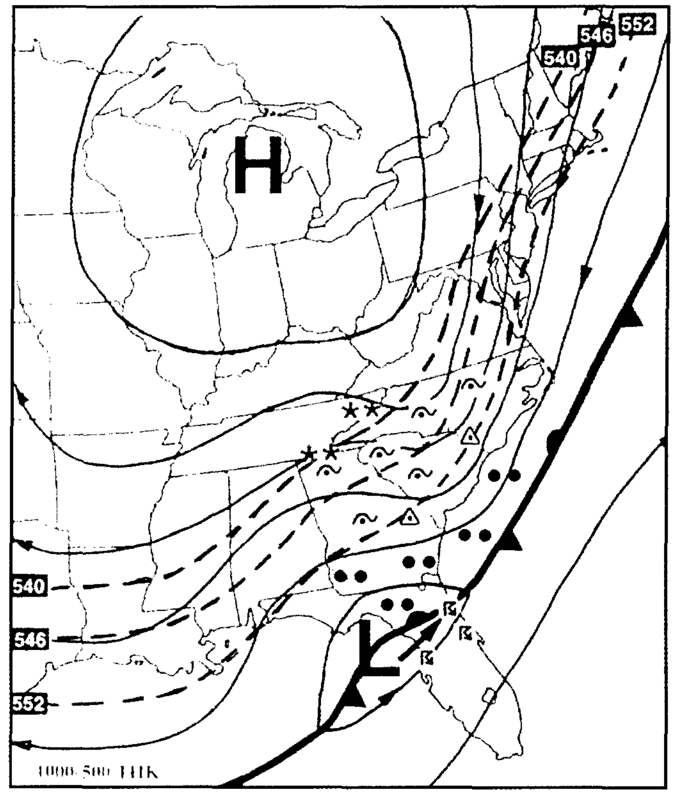

Figure 5-121. Southeastern CONUS Freezing Precipitation Situation – Day 1

The accompanying precipitation shown in Figure 5-121 is typical with these coastal lows. Moderate to heavy rain will occur within the warmer air along the coastal areas, while a few miles west, moderate to heavy snow is the rule. One or two of these storms may evolve into a "Nor'easter" (see Chapter 6) depending on system deepening and subsequent cold air advection.

On Day 2, Figure 5-122, the deepening surface low moves northeastward parallel to the coastline. Explosive intensification is often noted in the Cape Hatteras area.

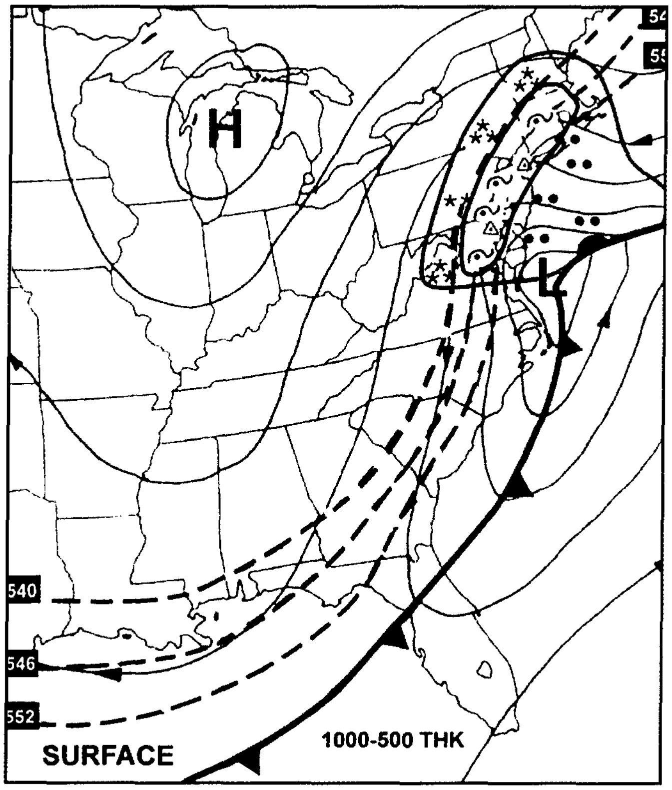

Figure 5-122. Southeastern CONUS Freezing Precipitation Situation – Day 2

As shown earlier in Chapter 5, under Lower Mississippi and Gulf of Mexico cyclogenesis, the southern branch of the polar jet lies across the southern CONUS/northern Gulf of Mexico region. Usually a long-wave trough lies across the central CONUS. Short waves bottom out in the long wave over the Ohio Valley southward into the Lower Mississippi River valley areas and provide upper support for coastal low deepening.

Case Studies

Selected Significant Winter Storms Case Studies

Selected case studies of significant winter storms that affected the eastern CONUS are included in this chapter. As the reader will see, pattern recognition is very important in the decision if a major storm will affect their location. The model guidance often provides excellent forecasts on the development of these major storms. The forecast problem lies in the future track of these storms. In these examples, similar upper-level features evolved when the long wave was located east of the Mississippi River. They are:

- A building upper ridge over western Canada and the western CONUS.
- A long wave trough over the central CONUS moving eastward.
- The merger of the southern and northern branches of the polar jet.
- Two positive vorticity and associated height fall centers approaching each other from different directions.

Development of a Nor'easter – Example 1

The northeastern CONUS may be affected by intense storm systems at any time of the year; however, they are more frequent and violent during the winter season. These intense storms systems, commonly referred to as "Nor'easters," are often accompanied by heavy snowfall over the northeastern CONUS.

In most occurrences, Nor'easters develop along frontal boundaries south of 40° north and east of the Appalachian Mountains, usually near the coastal areas. These systems move northward to northeastward and reach maximum development near the New England area. Usually storm development occurs when a frontal system approaches the southeastern CONUS from the west or southwest.

The following example typifies one of the most favorable synoptic patterns for coastal storm and extensive snowfall over the eastern CONUS: cyclogenesis along the polar front in the Gulf of Mexico. Frequently, when a large polar air mass prevails over the central CONUS (Figure 6-1), Pacific mP fronts moving across the southern Rockies become weaker as they encounter the stagnant air mass east of the Rocky Mountains. These fronts are typically discontinued on surface analyses. The surface frontal features under such a prevailing high regime would likely feature a stationary (or become stationary) polar front lying east to west across the Gulf of Mexico as shown in Figure 6-1.

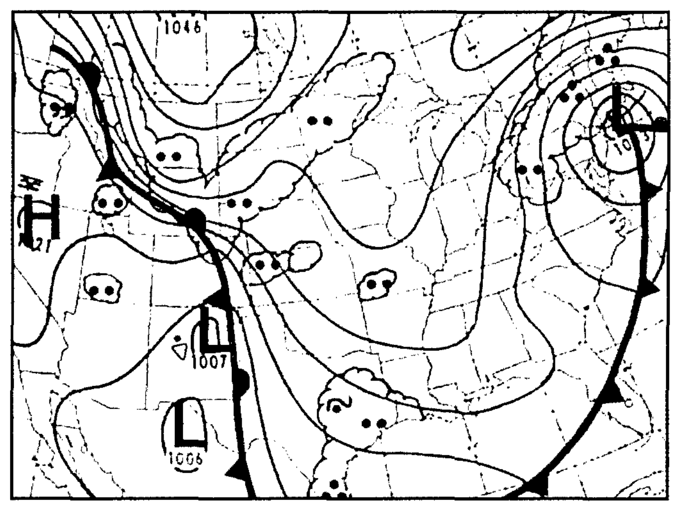

Figure 6-1. Surface, 1200Z/18 January 1978

When a short wave from the southern Great Plains approaches the dome of cold air (Figure 6-2), the Pacific front goes aloft and is difficult to locate on the surface analysis. Be suspicious of increasing cloudiness and precipitation within the polar ridge along the Gulf Coast and adjacent water areas (Figure 6-1).

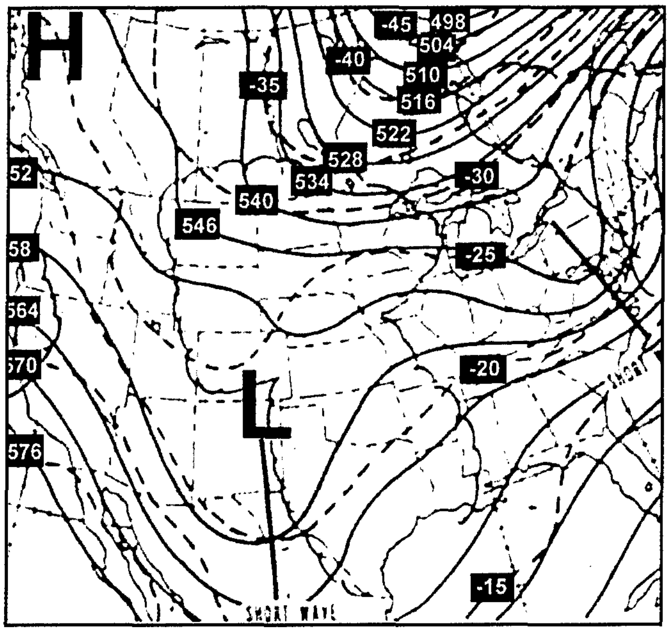

Figure 6-2. 500 mb, 1200Z/18 January 1978

These intensifications of clouds and precipitation are most likely a warning of subsequent frontal cyclogenesis of an East Gulf Low along the stationary front (Figure 6-3). In Figure 6-3, increased overrunning north of the frontal zone is noted. Considerable moisture appears at the 500 mb level (scalloped area in Figure 6-4) prior to and during frontal cyclogenesis (Figures 6-2 and 6-4).

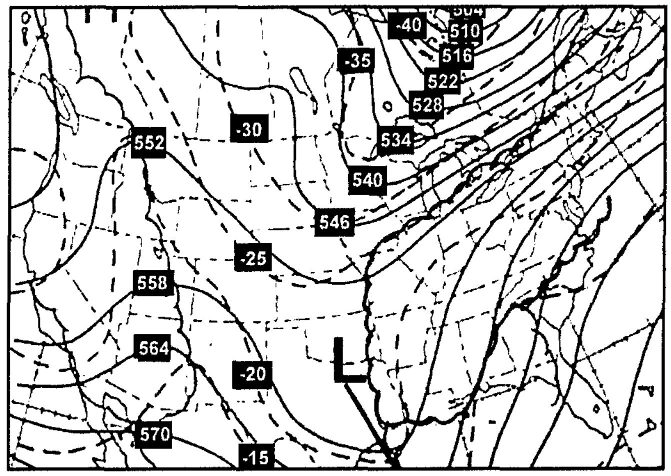

Figure 6-4. 500 mb, 1200Z/19 January 1978

On the third day, Figures 6-5 and 6-6, the East Gulf Low has moved northward and appears along the Atlantic Seaboard. Heavy snow, driven by winds up to 55 knots, buried the northeastern CONUS (15-20 inches). This regime may repeat itself when polar air prevails and a succession of short wave troughs, moving across the southern Rockies and Great Plains, generate frontal waves in the Gulf of Mexico (Figure 6-2 and 6-6). As in most cases of intense East Coast storms, the short wave becomes a negative tilt system as shown in Figure 6-6.

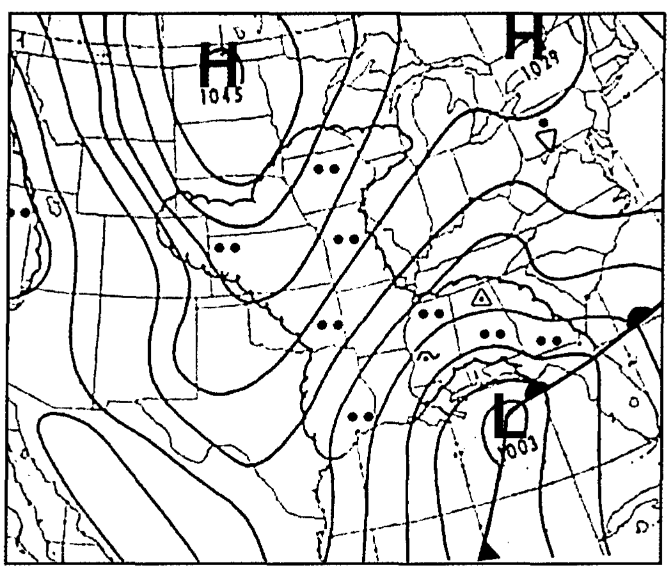

Figure 6-3. Surface, 1200Z/19 January 1978

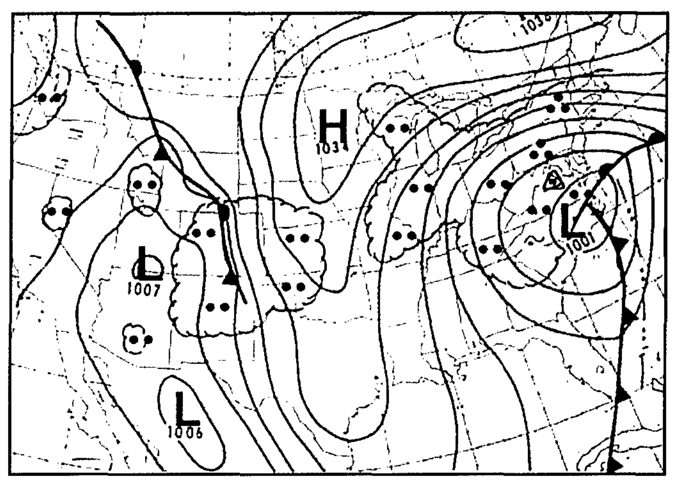

Figure 6-5. Surface, 1200Z/20 January 1978

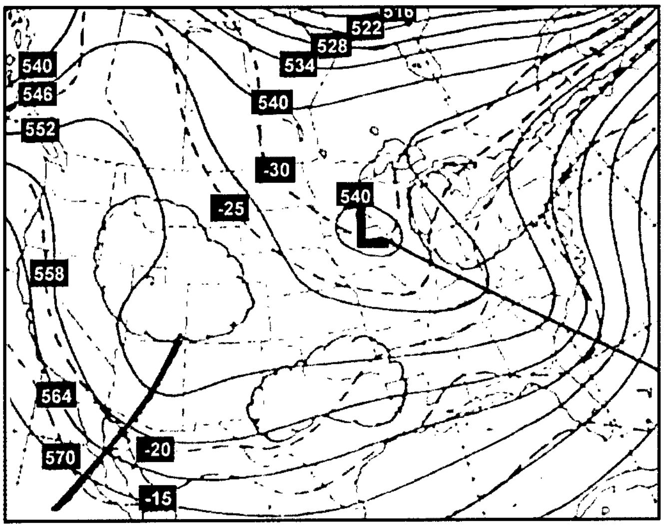

Figure 6-6. 500 mb, 1200Z/20 January 1978

Development of a Nor'easter – Example 2

In the preceding example, development of a Nor'easter was shown, starting over the Gulf of Mexico and moving up the Atlantic Seaboard. Coastal lows, however, can form in many different synoptic events. This example will show how a weak low located off the coast of the Carolinas on Day 1 developed into an intense coastal low that produced a blizzard over the northeastern CONUS within 24 hours.

Earlier in this TN (Chapter 2, Figures 2-11 through 2-13), it was shown that a cold core low usually exists over the Hudson Bay region and a long wave trough extends southward across the eastern one-third of the CONUS. Short waves from Canada drop southward across the Great Lakes then swing eastward to northeastward after they emerge from the long wave trough. Explosive cyclogenesis and intensification may occur, especially off shore over the warm Atlantic waters as the short wave moves eastward (northeastward) out of the long wave. The following sequence of events depicts the above actions.

In Figure 6-7, the 500 mb low developed near the southern tip of Hudson Bay 12 hours earlier (not shown). The low continued southward as shown in Figure 6-7. The position of the height fall center track (dashed line) and current height fall center (**X**) are shown in Figure 6-7. Figure 6-8 shows the surface conditions. A frontal system with two weak lows along it is approaching the East Coast. A weak low appears offshore; this low is to become the primary low.

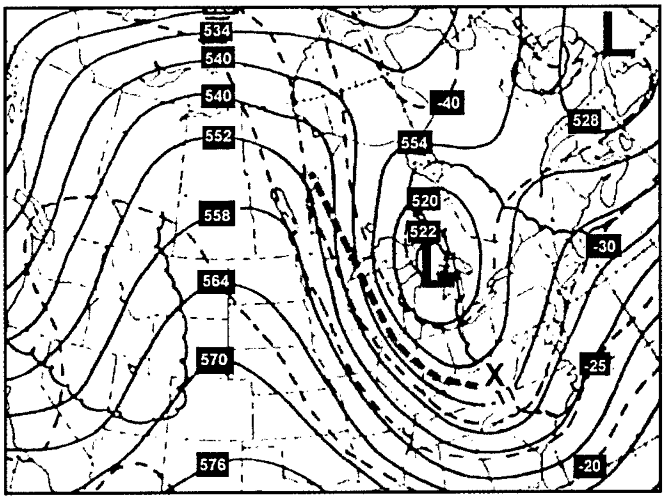

Figure 6-7. 500 mb, 0000Z/6 February 1978

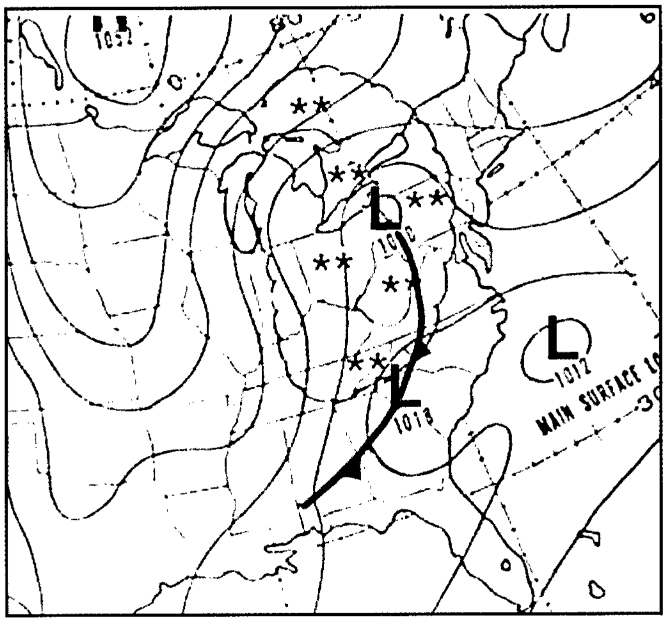

Figure 6-8. Surface, 0000Z/6 February 1978

During the next 12 hours, the upper low continued to dig southward as shown in Figure 6-9. Note that the height fall center has moved eastward into Virginia indicating recurvature. The surface low, located offshore in Figure 6-8, has organized and appears as a significant storm (Figure 6-10).

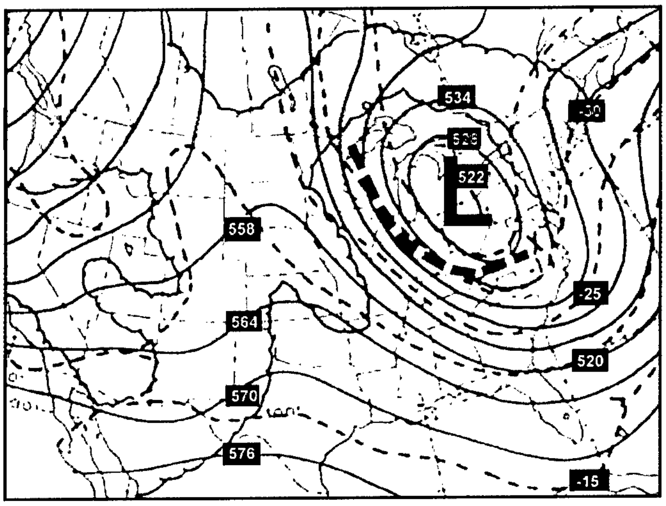

Figure 6-9. 500 mb, 1200Z/6 February 1978

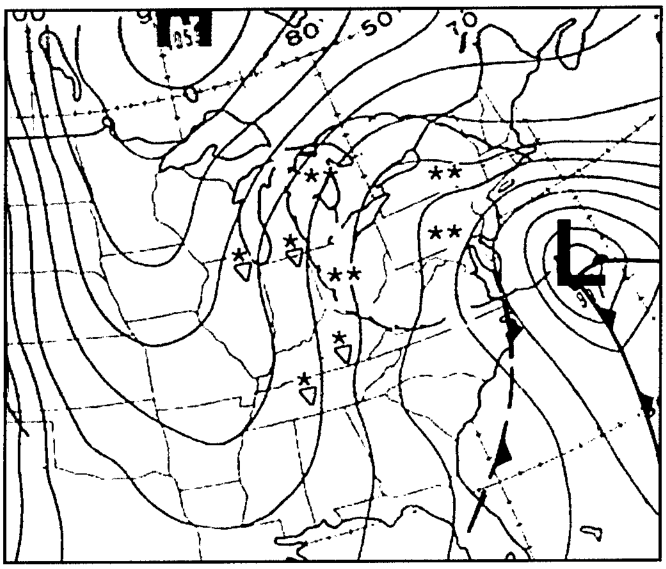

Figure 6-10. Surface, 1200Z/6 February 1978

Finally, in Figures 6-11 and 6-12, the storm system has become a vertically stacked system and a blizzard raged across the northeastern CONUS. The offshore low shown in Figure 6-8 moved northwestward towards the New England coast in response to the approaching upper-level low. Parts of Boston were blacked out; New York City struggled with 17 inches of snow and coastal towns were flooded by wind-driven surf.

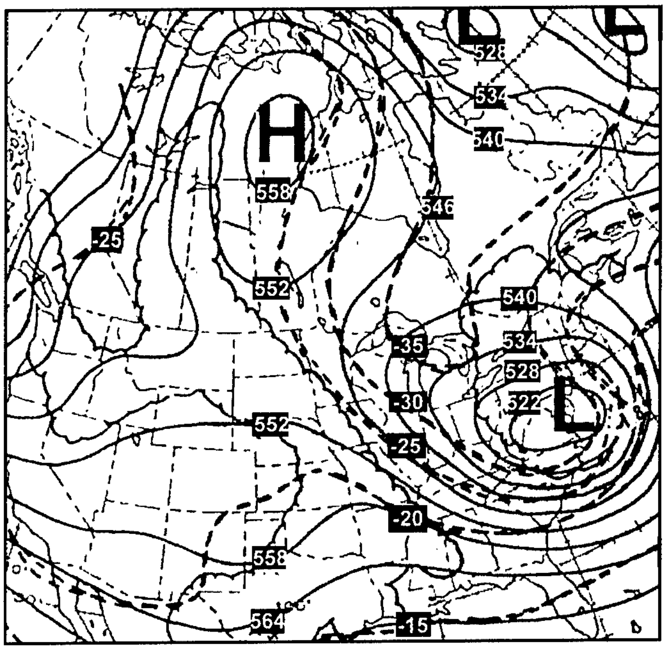

Figure 6-11. 500 mb, 0000Z/7 February 1978

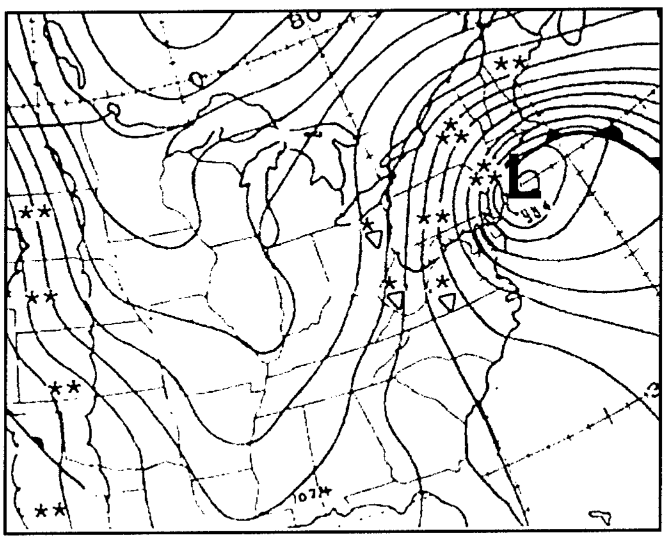

Figure 6-12. Surface, 1200Z/7 February 1978

Merging Height Fall/Vorticity Centers – Example 1

Residents located in the upper Midwest, Great Lakes and Ohio Valley experienced a giant, vicious storm system during 26-27 January 1978 which left scores dead, thousands stranded and widespread power failures. In Ohio, the storm was labeled the worst blizzard in their state's history. Record low-pressure readings were observed along the storm center's path through Ohio. Model data (LFM) was not saved; all information presented is from analyses.

What atmospheric changes led to such an immense storm system such as this? Indeed, there were many factors to be considered. In this chapter, a brief look at synoptic features prior to and during storm development will be shown. Some synoptic features observed were:

- A building upper ridge over the western Canada and western CONUS region.
- A long wave trough over the central CONUS moving eastward.
- Two jet-stream systems that merged over the Ohio Valley.
- Two positive vorticity systems and associated height fall centers approaching each other from different directions.
- Moisture-laden air from the Gulf of Mexico and Atlantic Ocean extended north and west to the Great Lakes.
- Polar air was streaming southeastward from the upper Midwest.

In Figure 6-13, two jet stream systems with their associated maximum isotach are shown. A pronounced north to south ridge is located off the western Canadian-CONUS coast as shown in Figure 6-14. Two height fall centers (HFCs) are noted in Figure 6-14, -10 (-100 meters) over Minnesota and –09 (-90 meters) over southern Arizona. Both HFCs are moving southward instead of their usual eastward direction. Height fall center movements towards the south are warnings of further deepening. The 500 mb low shown over Arizona usually poses a threat for heavy snowfalls over the Great Plains, however, this system behaved differently due to the short wave impulse in Canada.

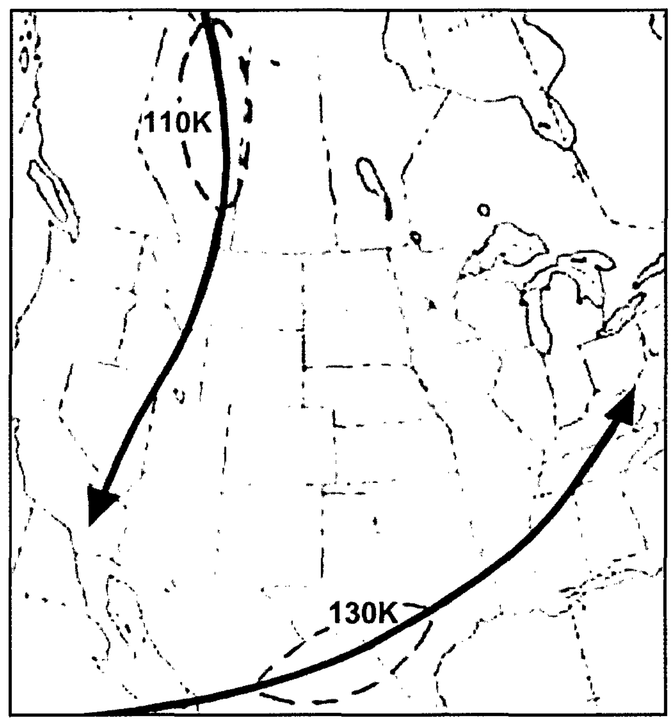

Figure 6-13. 300 mb Jets, 1200Z/24 January 1978
Northern and southern branches.

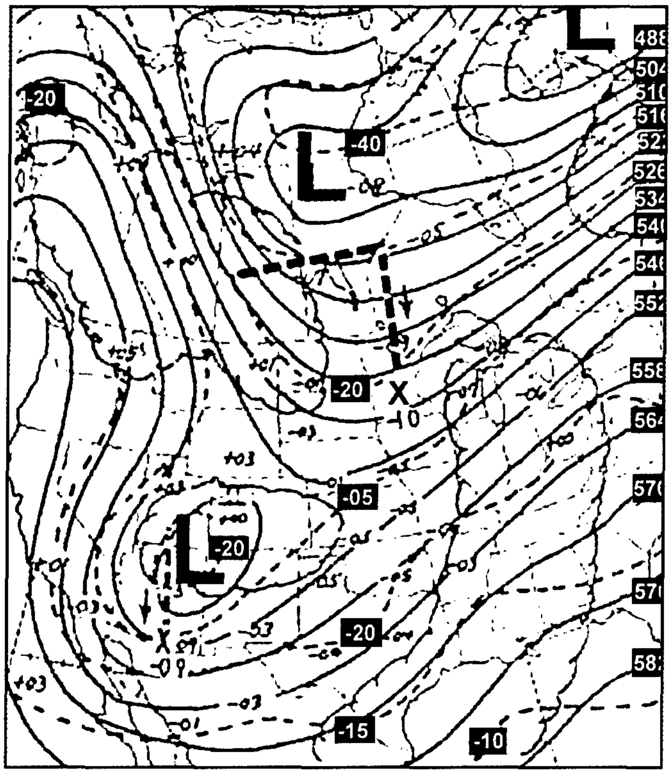

Figure 6-14. 500 mb, 1200Z/24 January 1978

The surface chart 12 hours later (Figure 6-15) reveals a typical frontal wave system. An extensive area of precipitation (mostly rain) extends from the Gulf Coast to Ohio. Note cP cold front over the upper Great Plains

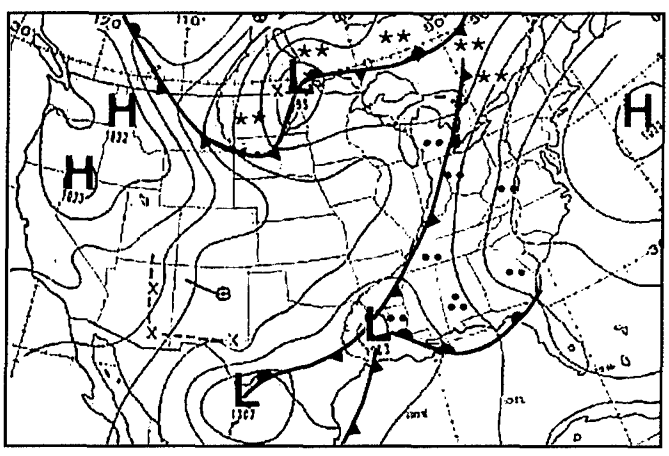

Figure 6-15. Surface, 0000Z/25 January 1978

Twenty-fours later in Figure 6-16, the HFC over South Dakota increased to –23 and had shown a slow, erratic path as deepening continues. The southern system's HFC also increased (-17) as it moved eastward. The 500 mb low centered west of Hudson Bay in Figure 6-14, moved southward to North Dakota during the past 24 hours. The related surface features shown in Figure 6-17 are not too different from 12 hours earlier (Figure 6-15). In Figure 6-17, note the HFC movements as shown by the dashed tracks and also indicated by the arrows. The northern center's movement southward and the Texas' center eastward track would, in time, either appear to merge or a transfer of energy from one system to the other.

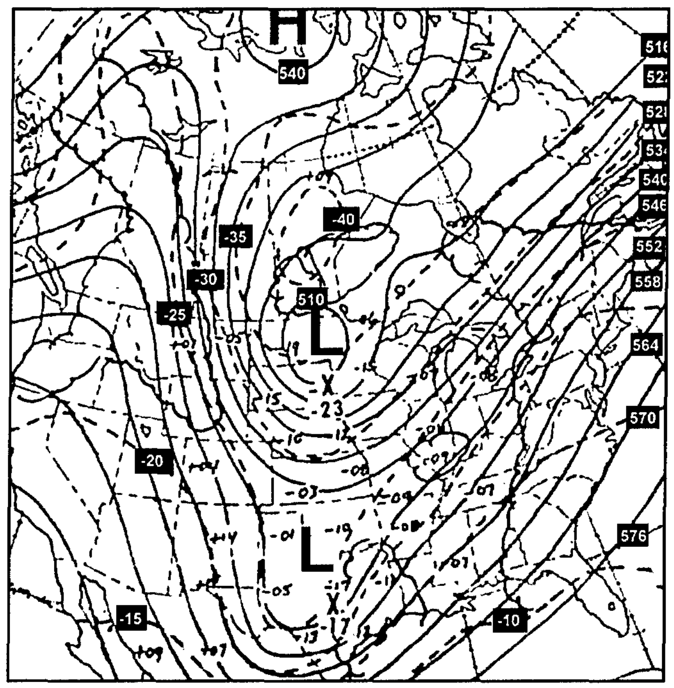

Figure 6-16. 500 mb, 1200Z/25 January 1978

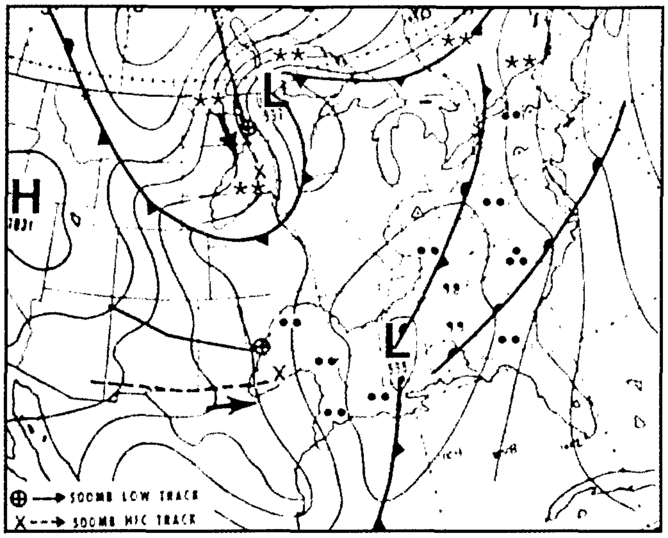

Figure 6-17. Surface, 1200Z/25 January 1978

Figure 6-18, 24 hours later than Figures 6-16 and 6-17, reveals only one strong HFC (-34) over West Virginia. Apparently the two HFCs shown in Figure 6-16 merged as did the two jet streams shown initially in Figure 6-13 and finally in Figure 6-19. This has been found to be a common HFC pattern during East Coast "superstorms" formation. Figure 6-20 shows the end result: a gigantic storm system over the Great Lakes. The low's central pressure fell 40 millibars in 24 hours—a true superstorm!

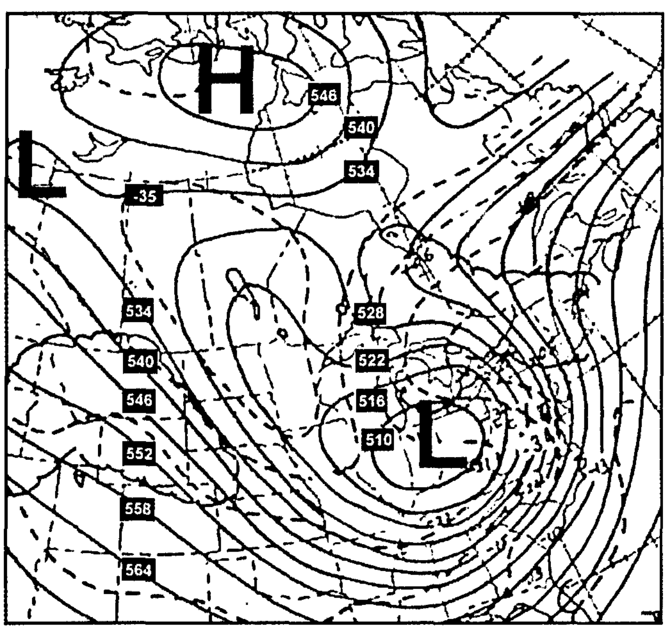

Figure 6-18. 500 mb, 1200Z/26 January 1978

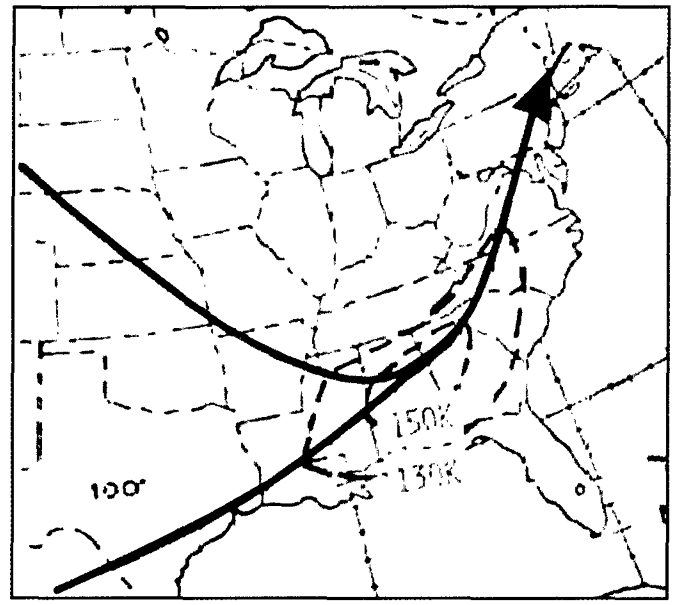

Figure 6-19. 300 mb Jets, 1200Z/26 January 1978
Southern and northern jet branches merged.

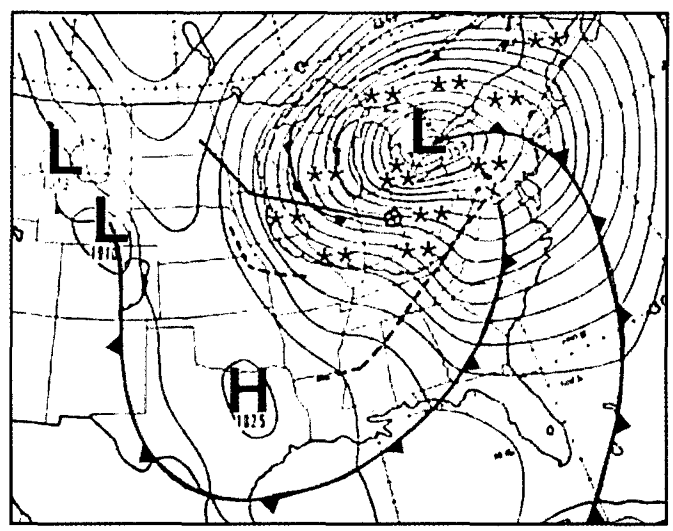

Figure 6-20. Surface, 1200Z/26 January 1978
A storm for the record book! Lowest central pressure recorded was 958 millibars.

Merging Height Fall/Vorticity Centers – Example 2

This storm system (9-11 January 1977), which spread a hefty blanket of snow across a large area from the Lower Mississippi Valley northeastward to the Great Lakes, was not as intense as the 24-25 January 1978 superstorm described in Example 1. The development, intensification and movement of this second example were, however, similar in many respects to the superstorm—both in the upper levels and at the surface.

All of the upper features highlighted on page 6-1 can also be used in this example. They were:

- A building upper ridge over western Canada and the western CONUS.
- A long-wave trough over the central CONUS moving eastward.
- Two jet streams which merged over the Ohio Valley.
- Two positive vorticity and associated height fall centers approaching each other from different directions.

There was one notable surface synoptic difference between these two examples: the location of anticyclones prior to and during storm development. In Example 1, the primary anticyclone was mP and located well offshore and southerly flow produced mostly rain (receding high-pressure pattern). In Example 2, however, a large stationary cP high prevailed over the central CONUS that produced mostly snow (prevailing high-pressure pattern Figure 6-23).

Figures 6-21 and 6-22 illustrate the 300 mb and 500 mb patterns during the initial development period. Compare the striking similarities between both examples' upper air patterns (Figures 6-16 and 6-22). In Figure 6-22, two short waves with their associated HFCs appeared over Canada (-10 moving southward) and over the southern Rockies/Plains (-14 moving eastward). The two hatched boxes shown in Figure 6-22 represent favorable 500 mb cyclogenesis areas

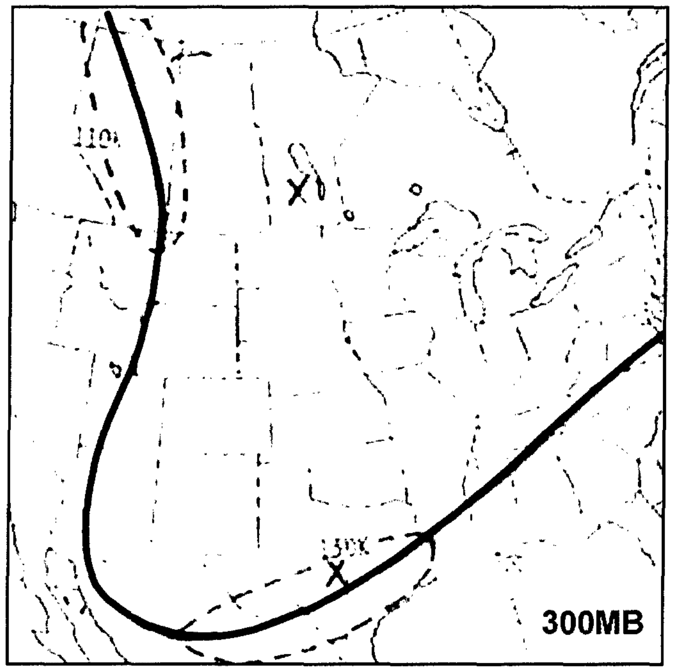

Figure 6-21. 300 mb Jets, 1200Z/9 January 1977

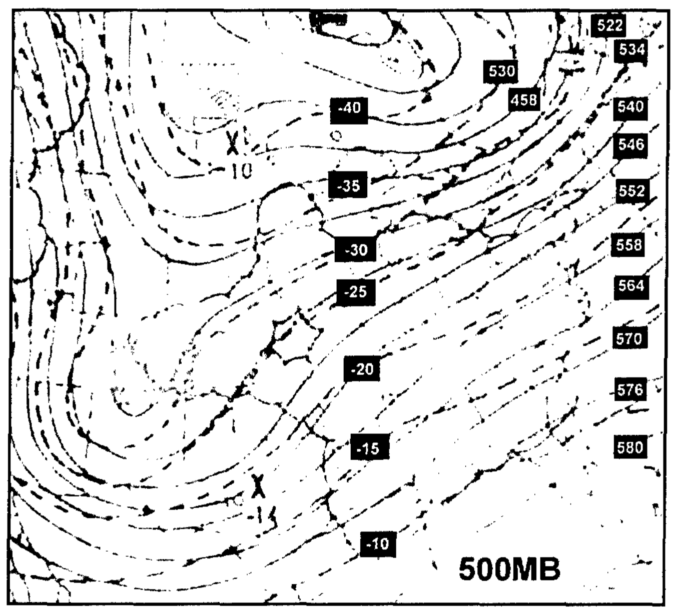

Figure 6-22. 500 mb, 1200Z/9 January 1977

At the surface in Figure 6-23, widespread overrunning within the cold air is laying a blanket of light to moderate snow across the Southern Plains towards the Ohio Valley. A strong Gulf flow overrunning the polar air across the Ohio Valley is noted in Figure 6-23.

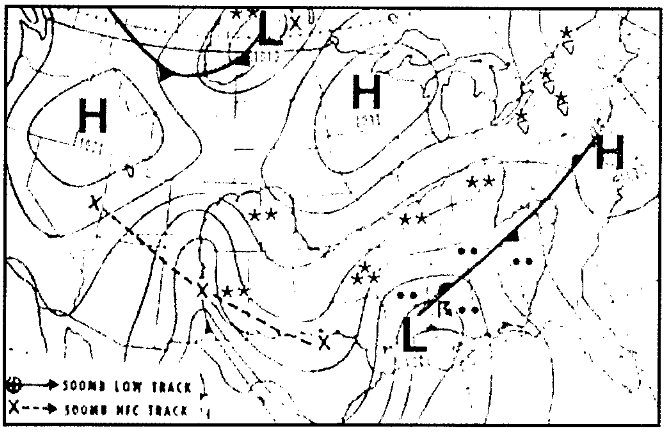

Figure 6-23. Surface, 1200Z/9 January 1977

Twelve hours later, Figures 6-24 and 6-25 show the 500 mb and surface conditions. In Figure 6-24, note continued HFC movements from the north and west; both centers have increased in magnitude values. In Figure 6-25, snowfall continues within a disorganized frontal system marked by the surface trough located in eastern Tennessee and Kentucky

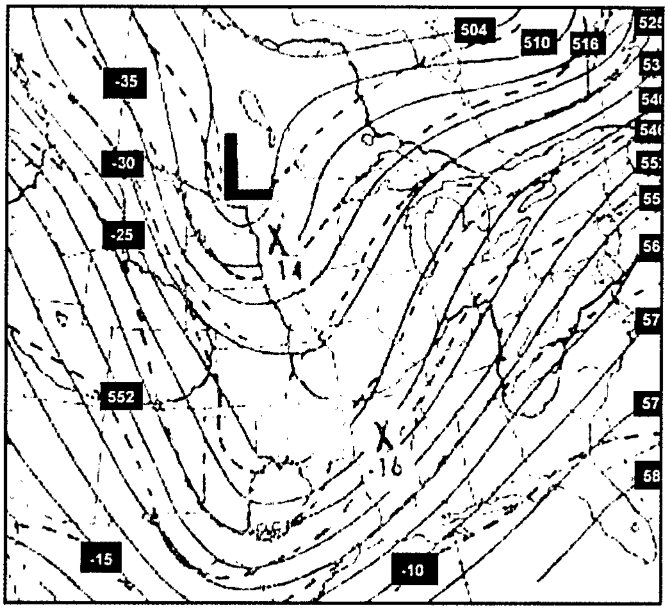

Figure 6-24. 500 mb, 0000Z/10 January 1977

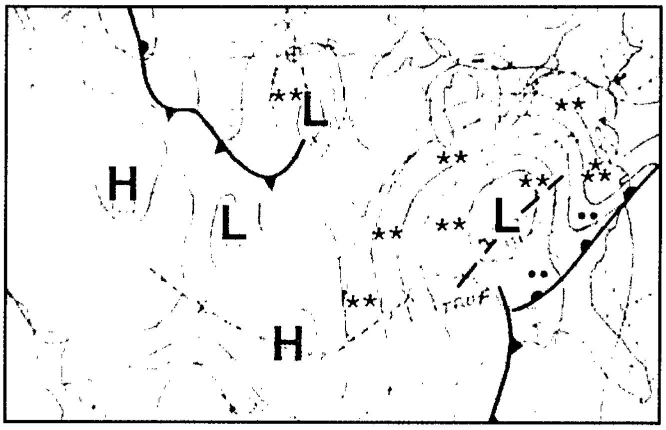

Figure 6-25. Surface, 0000Z/10 January 1977

Figures 6-26, 6-27 and 6-28 indicate the changing upper and surface conditions 12 hours later. In Figure 6-26, the northern and southern branches appeared to have merged over northern Georgia with a 150-knot jet max. Only one HFC (-25) is shown on the 500 mb analysis (Figure 6-27); apparently the two HFCs shown previously have merged. The 500 mb low that developed earlier within the hatched area (Figure 6-24) has moved southeastward into Minnesota.

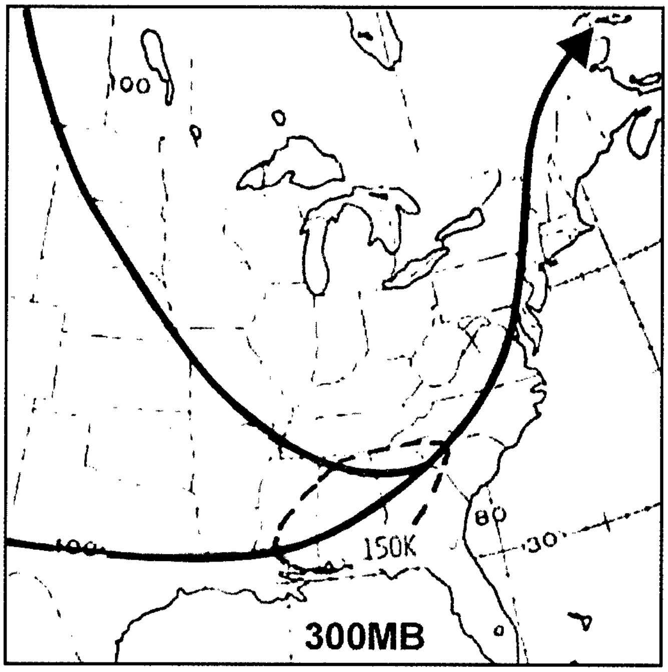

Figure 6-26. 300 mb Jets, 1200Z/10 January 1977

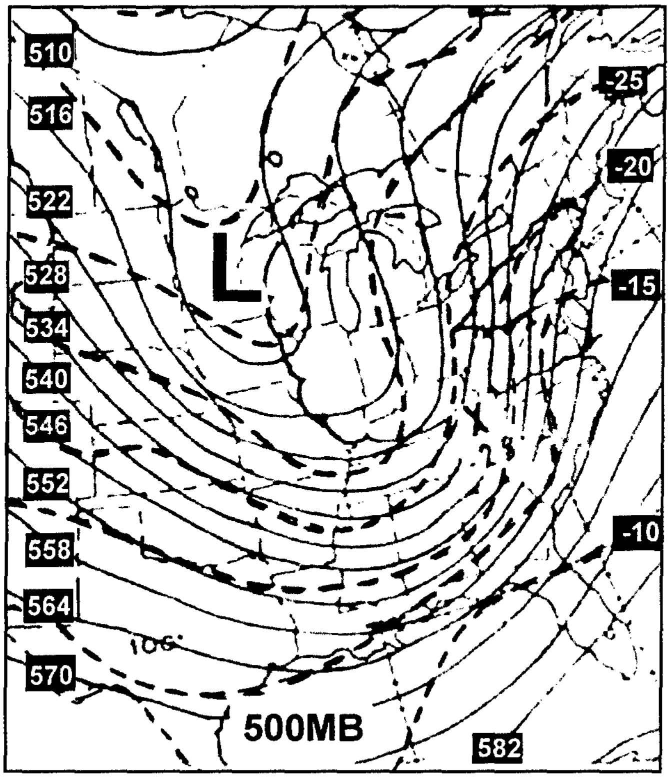

Figure 6-27. 500 mb, 1200Z/10 January 1977

At the surface, two lows are shown in Figure 6-28. The low over Lake Erie that was over the upper Great Plains in Figure 6-25 (associated with the northern short wave) is dissipating as a new frontal low forms off the Virginia coast. The development of the Virginia low is most likely associated with the southern short wave. Precipitation has become widespread as shown in Figure 6-28. The heavy snowfall area appears to be lying to the left of the approaching 500 mb HFC track. Note the HFC track indicated by **X** in Figure 6-28. The Northern Plains cP cold front shown earlier in Figures 6-23 and 6-25 has dissipated as it merged with the Atlantic coastal storm (Hatteras Low).

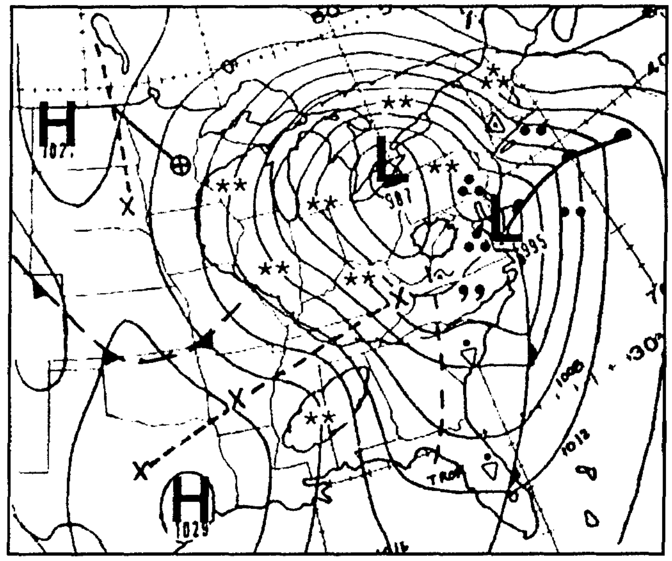

Figure 6-28. Surface, 1200Z/10 January 1977

In the last set of figures, the storm system has become fully organized over New England. In Figure 6-29, the 500 mb low has continued southeastward and has connected with the –31 HFC associated with the southern branch of the polar jet. The coastal low which was off the Virginia coast has become the dynamic low and has deepened 13 millibars during the past 12 hours as shown in Figure 6-30.

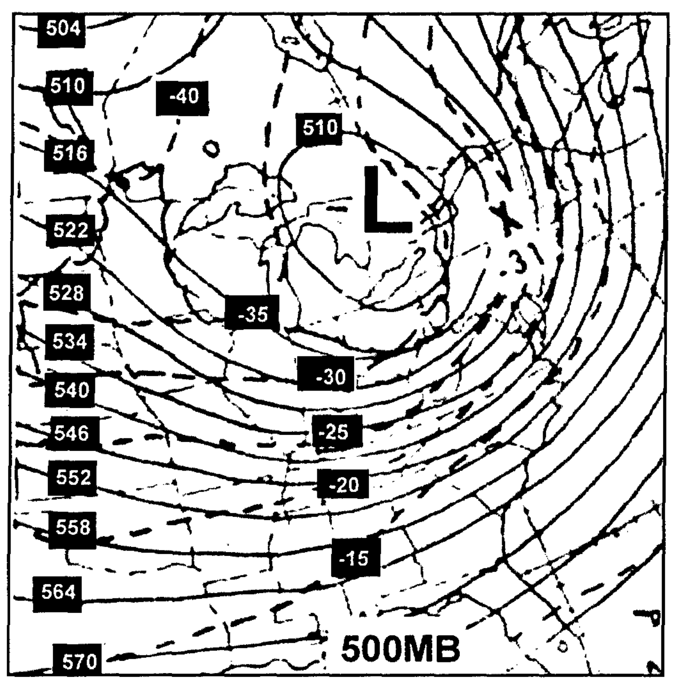

Figure 6-29. 500 mb, 0000Z/11 January 1977

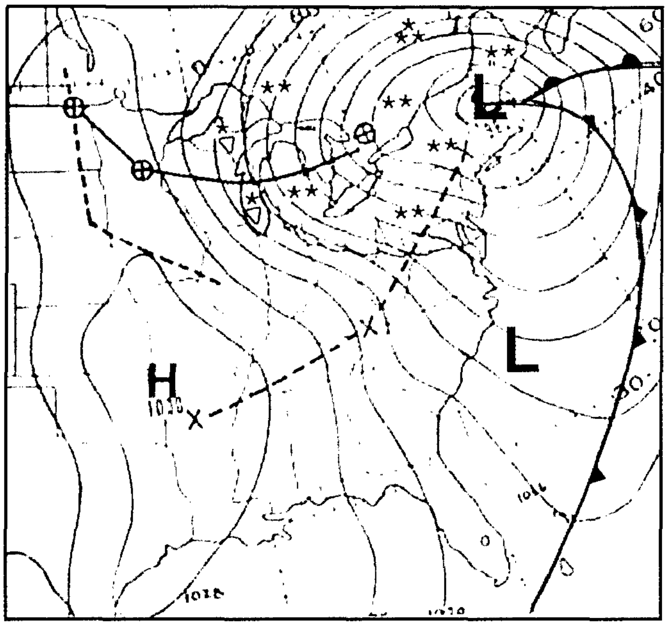

Figure 6-30. Surface, 0000Z/11 January 1977

These two case studies (Examples 1 and 2) were remarkably similar. The structures of the storms through development stages were nearly identical. Merging positive vorticity and height fall centers, merging jets, intense surface storms indicated the likelihood of widespread heavy snowfall. In Example 1, the result was a super storm that produced unparalleled blizzard conditions over the Great Lakes and Ohio Valley. Note lowest central pressure of 958 millibars in Example 1. In Example 2, the central pressure was reported in the 980 millibars range – central pressures typical of great storms over the northeastern CONUS. Heavy snow occurred with this storm also but not nearly the extent of that observed with the super storm.

Only minor differences between the two examples occurred. The major difference was the existence of continental polar air in the development area of Example 2 and the existence of maritime polar (cool, wet) and, later, maritime tropical (warm, wet) in the development stages of the super storm. Use the concept of merging short waves within the long wave trough by following merging polar jets, merging positive vorticity and height fall centers to predict a significant storm. Use proven rules for forecasting the snow/no snow tracks (i.e. the 1000-500 mb 540-thickness isopleth) and look for other clues to determine when a real super storm is imminent.

Merging Height Fall/Vorticity Centers – Example 3

Here is one more case study of merging short wave systems. This was a huge snowstorm that affected a large region of the Midwest during early January 1999. In Chicago, 22 inches of snow fell at O'Hare International Airport from the New Year's Day through the early hours of 3 January 1999—the biggest total for a single storm since 23 inches fell during the blizzard in 1967. After the low passed the Great Lakes area, lake effect westerly winds produced another foot of snow in the snowbelt areas east and southeast of Lake Michigan and east of Lakes Erie and Ontario. Freezing rain, along the southern edge of the storm, began on New Year's Day over Arkansas and spread eastward across central and southern Missouri through Kentucky and West Virginia. Later, as the storm progressed northeastward, freezing rain affected East Coast areas from North Carolina to Maine.

Figure 6-31 depicts the height changes between 1200Z on 31 December 1998 to 0000Z on 1 January 1999 when the upper impulse was moving across the western CONUS (Twenty-four hours before major storm development over the Great Plains). Two short waves, one in Canada (moving south) and the other moving eastward over the Great Basin are identified by the two height fall centers shown in Figure 6-31. These systems are associated with the northern and southern branches of the polar jet

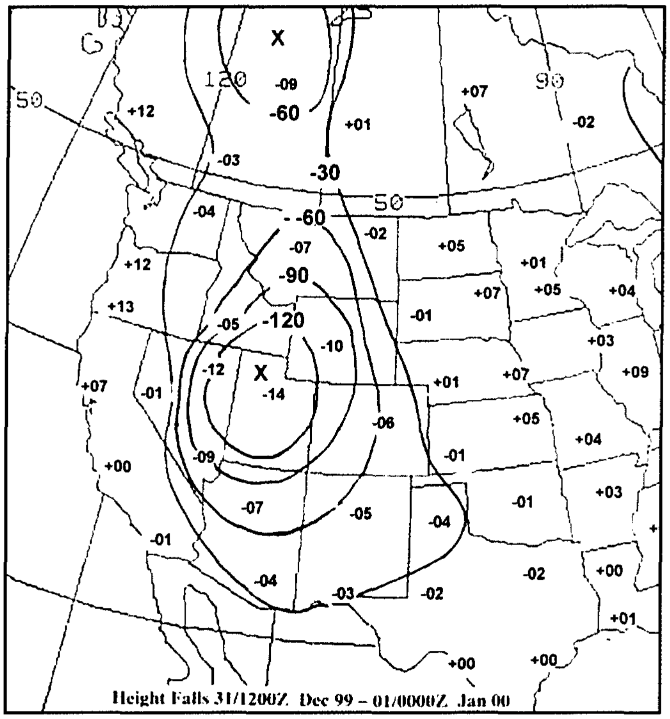

Figure 6-31. 500 mb Height Falls/Rises, 1200Z/ 31 December 1998-0000Z/1 January 1999
Height falls are in 30 meter increments. Note the two HFCs.

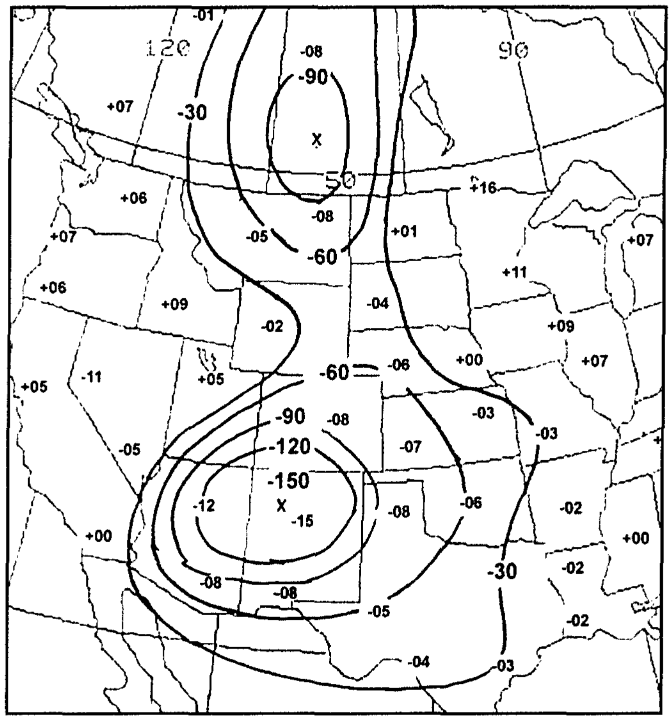

Figure 6-32. 500 mb Height Falls/Rises, 0000Z/ 1 January 1999-1200Z/1 January 1999
Two distinct HFCs associated with the northern and southern polar jet branches.

Figure 6-32 depicts height fall movements during the next 12 hours. The Canadian short wave is dropping southward into the northern CONUS. Figure 6-33 shows the initial 500 mb heights and vorticity analyses. Generally, height fall centers are located ahead of the associated positive vorticity centers.

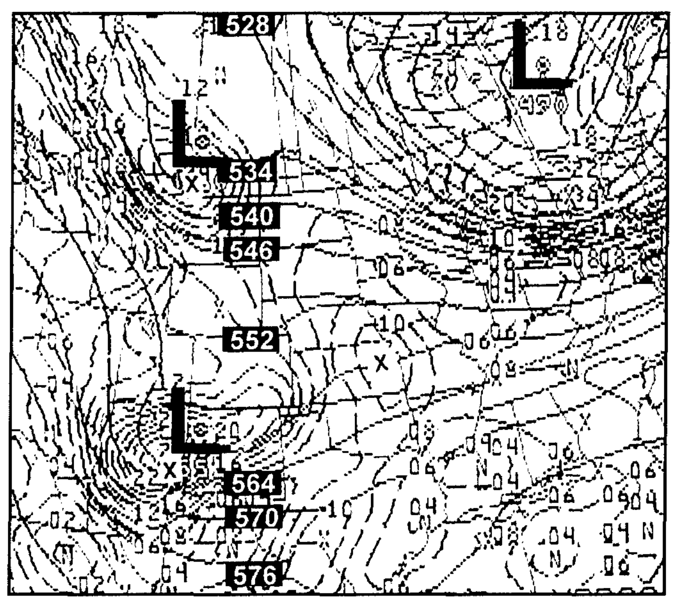

Figure 6-33. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/1 January 1999

The surface conditions depicted in Figure 6-34 show a large polar air mass over the central and eastern CONUS. The isobaric pattern over the Southern Plains and Lower Mississippi River Valley region is oriented southeast to northwest that indicates a favorable upslope flow for Gulf moisture advection into the developing storm. In Figure 6-34, freezing rain had developed over central Oklahoma and Kansas and spread eastward into central and northern Arkansas and Missouri as warmer air flowed over the shallow polar air. Freezing rain occurred between the 552 and 540 thickness ribbon. There was no surface low associated with the Canadian short wave although an inverted trough appeared below the short wave. The southern Rockies low is associated with the southwest CONUS short wave.

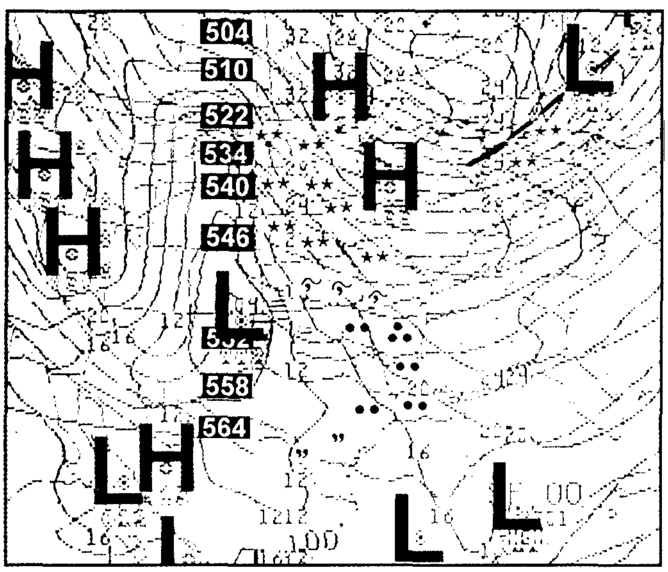

Figure 6-34. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/1 January 1999

At the 850 mb level (Figure 6-35), a south to north contour gradient indicates favorable Gulf moisture advection into the Great Plains. Freezing rain was occurring between the +5° C and -5°C 850 mb temperature ribbon over northern Oklahoma/Arkansas and northward (see the surface chart in Figure 6-34). Thunderstorms began over eastern Texas and western Louisiana during this period.

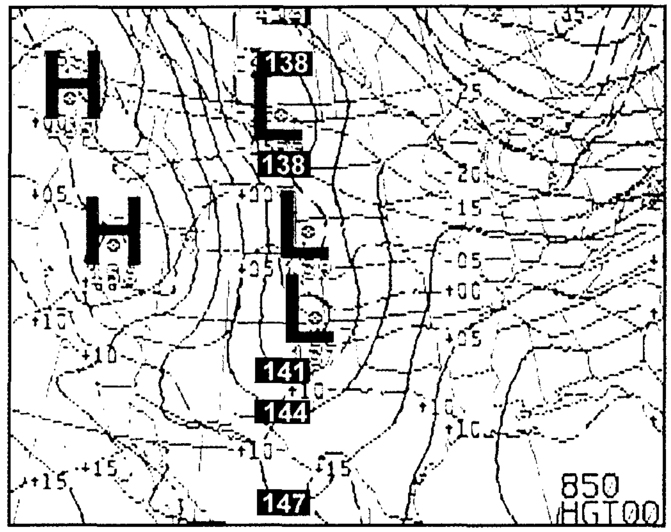

Figure 6-35. 00HR 850 mb HEIGHTS/TEMPS, 1200Z/1 January 1999

The next 12-hour set of analyses is shown in Figures 6-36 through 6-39. In the height fall/rise center analysis, Figure 6-36, the northern system continues southward. The southern system has moved southeastward within the long wave trough. The 500 mb analysis, Figure 6-37, shows the formation of a low within the northern short wave; this low will intensify as it continues southeastward and deepens (arrows denote the two short waves in subsequent 500 mb figures).

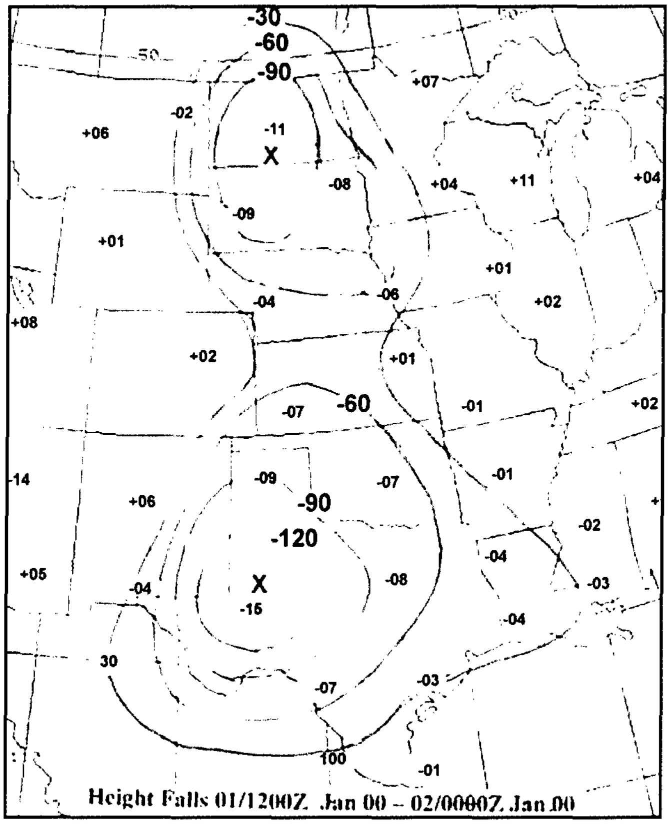

Figure 6-36. 500 mb Height Falls/Rises, 1200Z/ 1 January 1999 – 0000Z/2 January 1999

The surface analysis, Figure 6-38, shows a large area of precipitation over the central CONUS. Freezing precipitation has developed over Kansas and Missouri. Warm air advection, overrunning and the PVA shown earlier in Figure 6-33 and 6-34 contributed to the large precipitation area.

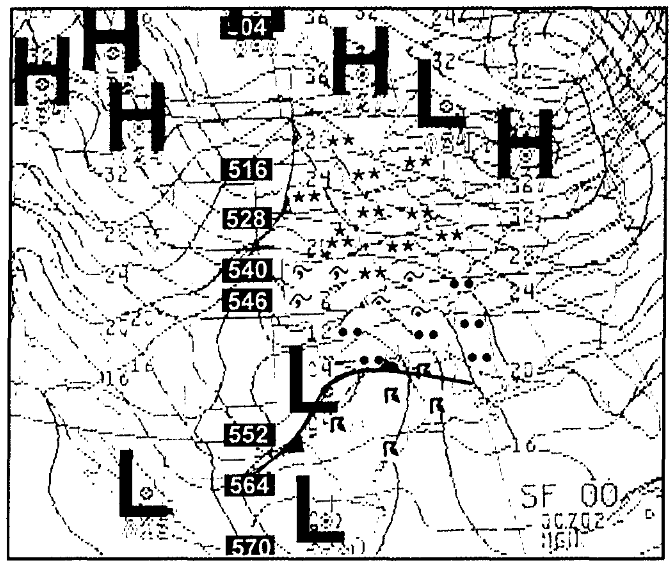

Figure 6-38. 00HR MSL PRES/1000-500 mb THKNS, 0000Z/2 January 1999
Primary low has moved into northern Texas.

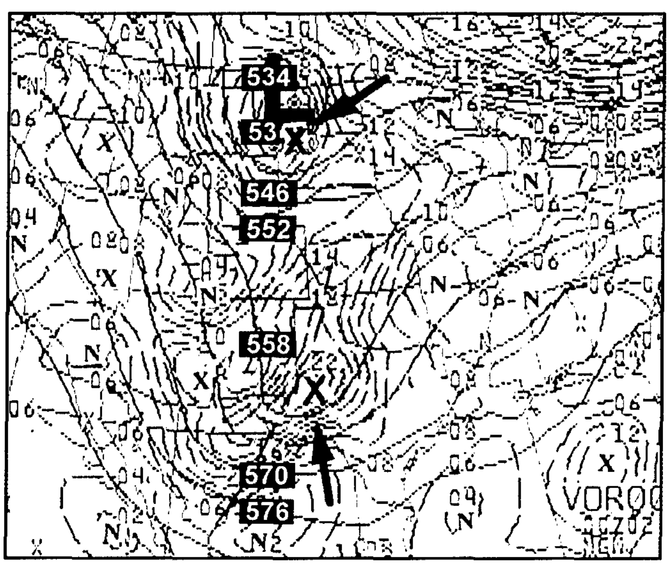

Figure 6-37. 00HR 500 mb HEIGHTS/VORTICITY, 0000Z/2 January 1999

Thunderstorms have broken out over eastern Texas and Louisiana within the low-level jet and moisture advection shown in the 850 mb analysis (Figure 6-40). Thirty-five severe thunderstorms and four tornadoes were reported between 00Z and 12Z over eastern Texas and Louisiana. Figure 6-39 depicts the NGM initial 850 mb data. A temperature ridge has developed over the Central Plains as warm air continues northward. Freezing precipitation is occurring within this thermal ridge.

Figure 6-40 shows the analysis over the central CONUS for the same valid time as shown in Figure 6-39. A thermal axis, low-level jet and Gulf moisture advection exists over the shallow polar air mass, consequently, strong overrunning is occurring as shown by the extensive precipitation in Figure 6-38.

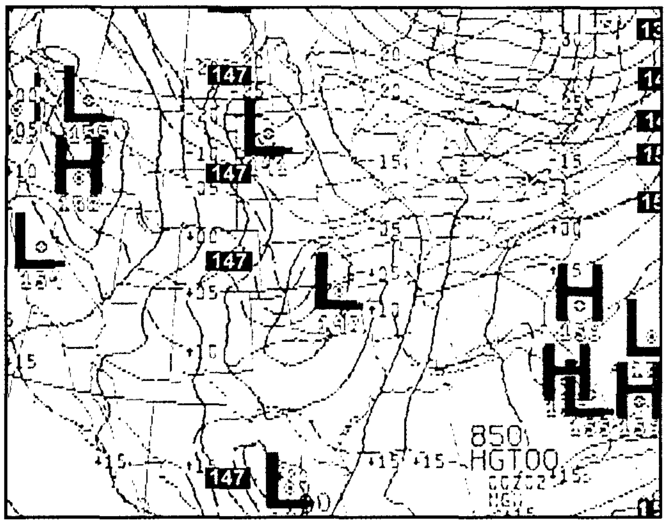

Figure 6-39. 00HR 850 mb HEIGHTS/TEMPS, 0000Z/2 January 1999
Although not shown in the surface chart (Figure 6-38), two lows now appear at the 850 mb level and are associated with the two short waves.

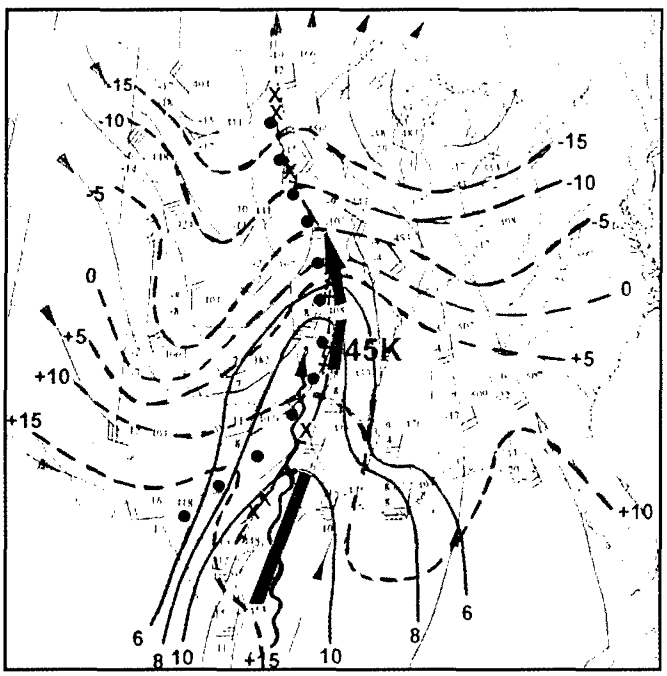

Figure 6-40. 850 mb Analysis, 0000Z/ 2 January 1999
40-45 knot low-level jet (LLJ) located within the thermal ridge. Gulf moisture advection extends northward into Missouri.

The next 12-hour set of analyses is shown in Figures 6-41 through 6-46. In the height fall/rise center analysis, Figure 6-41, the two height fall centers shown in previous analyses have merged into one system over the central CONUS. In Figure 6-42, two positive vorticity centers, associated with the two short waves, are shown over northern Nebraska and eastern Oklahoma. The height fall center, however, is located over northwestern Missouri between these two vorticity centers and apparently indicated merger of the two short wave systems.

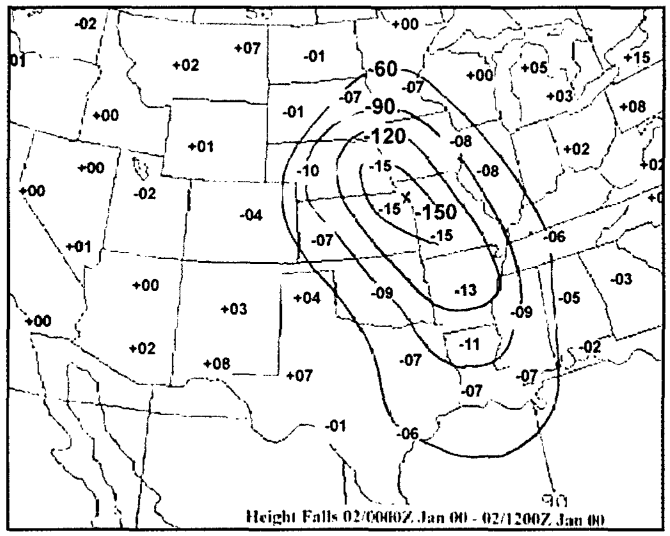

Figure 6-41. 500 mb Height Falls/Rises, 0000Z/ 2 January 1999-1200Z/2 January 1999

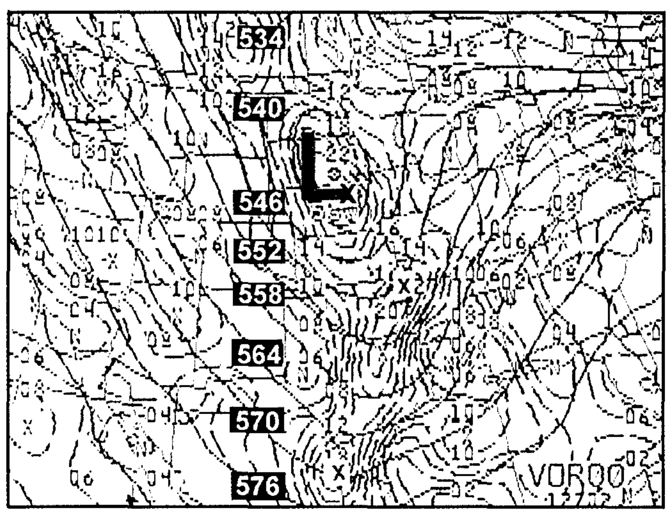

Figure 6-42. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/2 January 1999

The associated surface conditions are shown in Figure 6-43. The surface low moved from west Texas to southeastern Missouri in 12 hours as the associated short wave lifted northeastward. Freezing rain continued across central Missouri and Illinois. Frontal severe thunderstorms including four tornadoes continue over Louisiana and Mississippi. The Appalachian Cold Air Damming (CAD) Effect is noted over northern Georgia and northward east of the Appalachians by the polar ridge. This would be a prime area for freezing precipitation.

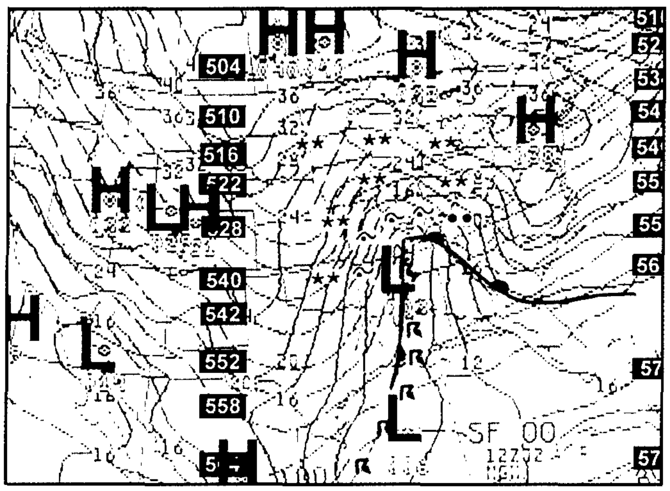

Figure 6-43. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/2 January 1999

In the NGM 850 mb chart, Figure 6-44, the low previously shown over North Dakota in Figure 6-39 has dissipated although a cold pocket of –25° C lies over the area. Freezing rain continued across central and southern Missouri and Illinois within the +5°C to -5°C 850 mb temperature ribbon.

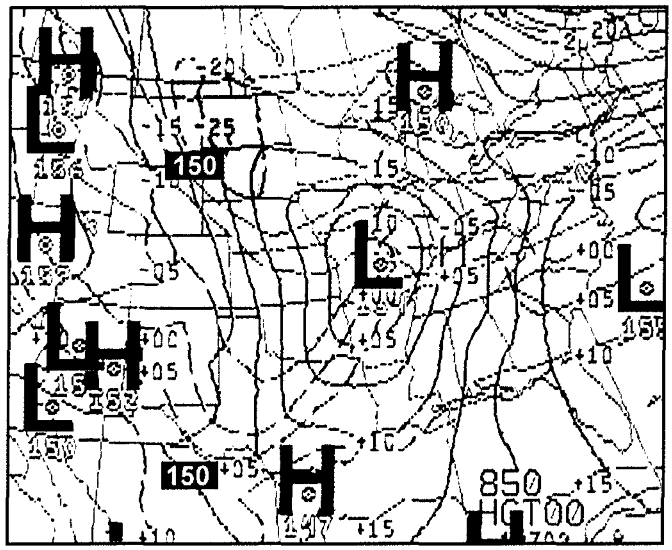

Figure 6-44. 00HR 850 mb HEIGHTS/TEMPS, 1200Z/2 January 1999

Freezing rain continues within the thermal ridge over Missouri and Illinois

The 850 mb analysis depicted in Figure 6-45 showed a continuing strong low-level jet, with a reported 60-knot jet max over Tennessee, and was advecting moist air into the central Missouri Valley area.

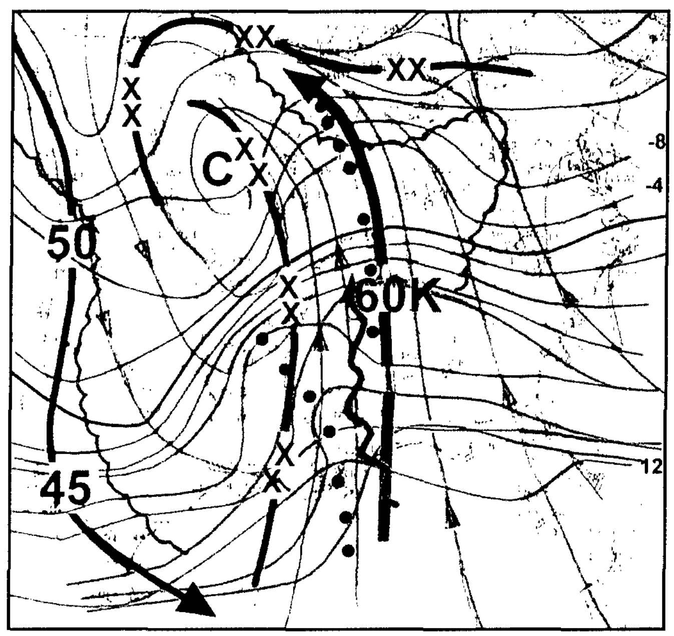

Figure 6-45. 850 mb Analysis, 1200Z/ 2 January 1999

Low-level jet has shifted eastward—60 knot jet max showed over Tennessee.

The 300 mb analysis, Figure 6-46, shows the long wave over the central CONUS. In the two previous examples, the northern and southern branches merged over the eastern CONUS; this did not occur in this event. Strong difluent flow can be seen over the Gulf Coast and northward that enhanced severe thunderstorm potential.

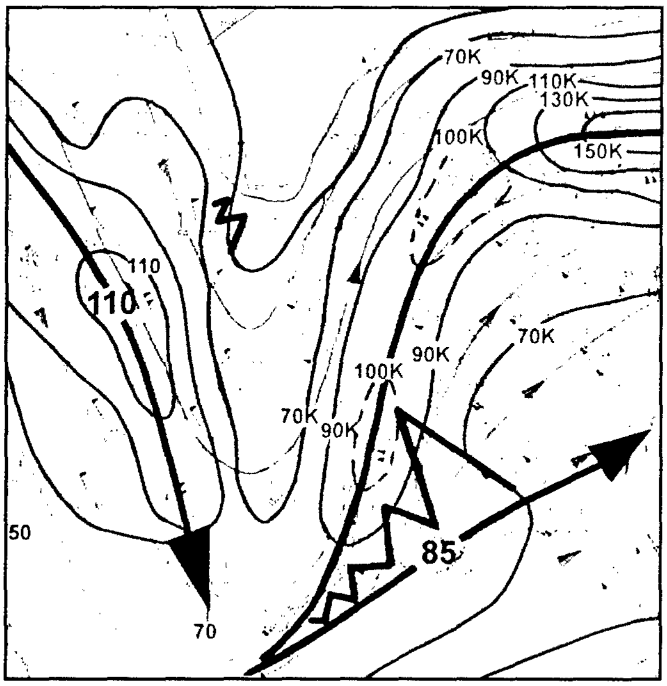

Figure 6-46. 300 mb Analysis, 1200Z/ 2 January 1999

Figures 6-47 through 6-49 illustrate the next 12 hours. In Figure 6-47, the magnitude of the height fall center increased to –18; the center moved from the Kansas City area to southern Minnesota. At the 500 mb level, Figure 6-48, the South Dakota low has dropped southeastward into southern Iowa. As in most cases, the height fall center (HFC) is to the east or northeast of the upper low dependent upon direction of movement. In this case, the HFC is northeast of the low that suggests the low should bottom out and lift northeastward.

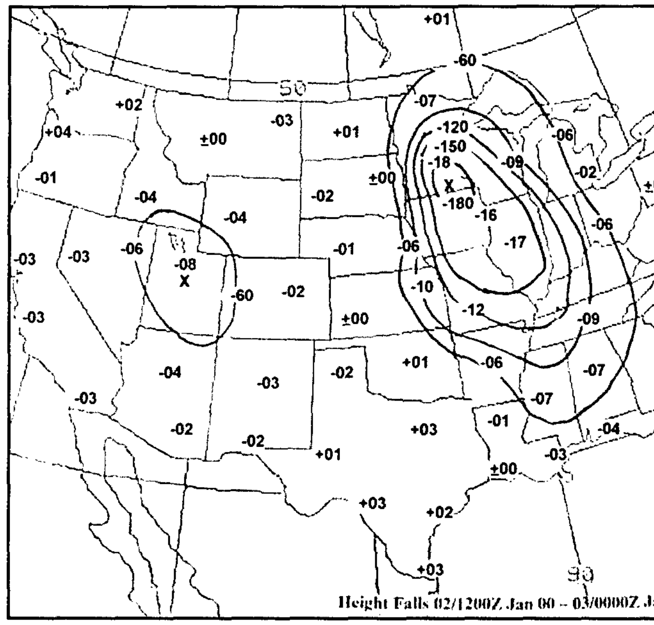

Figure 6-47. 500 mb Height Falls/Rises, 1200Z/ 2 January-0000Z/3 January 1999

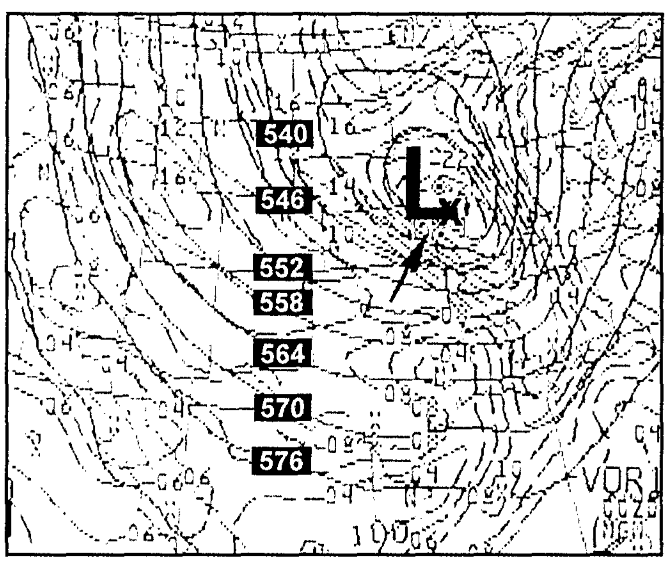

Figure 6-48. 00HR 500 mb HEIGHTS/VORTICITY, 0000Z/3 January 1999

In Figure 6-49, the surface low has deepened further and widespread precipitation is shown. Freezing rain has developed over the Appalachian Mountain region where shallow cold air is in place (damming effect that was mentioned in Figure 6-43). Heavy snow is falling over the Great Lakes region. Chicago ended up with almost 22 inches. The polar ridge over New England hasn't moved eastward much due to a stationary Atlantic low. These actions allow for cold air to remain in place with little, if any warm air advection.

The next 12 and 24-hour sets are shown in Figure 6-50 through 6-53. In the first 12-hour period, the 500 mb analysis, Figure 6-50, reveals that the low has lifted northeastward over Michigan. A PVA lobe is shown over eastern South Carolina and off shore. This impulse probably was the trigger for coastal low development over the DELMARVA region as shown in Figure 6-51 (appears to be triple point low formation). The freezing rain area has shrunk in areal coverage as southeasterly winds bring warmer air inland and has eroded the cold air.

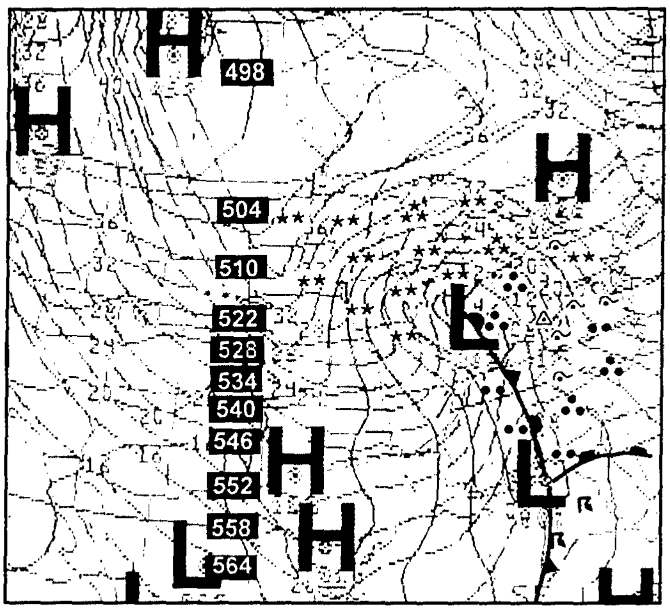

Figure 6-49. 00HR MSL PRES/1000-500 mb THKNS, 0000Z/3 January 1999

Severe thunderstorms occurred over southern Georgia and nearly all of Florida as the cold front moved through the region.

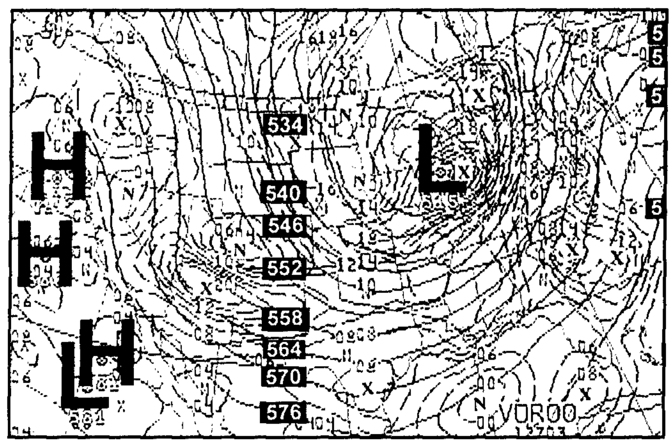

Figure 6-50. 00HR 500 mb HEIGHTS/VORTICITY, 1200Z/3 January 1999

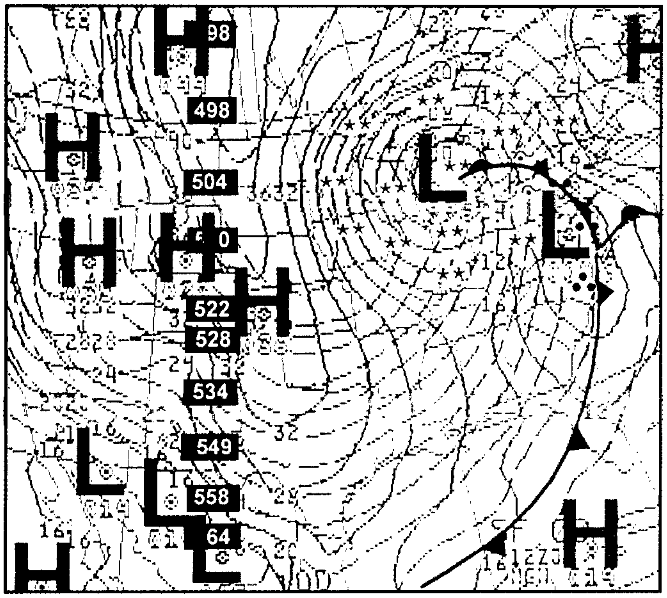

Figure 6-51. 00HR MSL PRES/1000-500 mb THKNS, 1200Z/3 January 1999

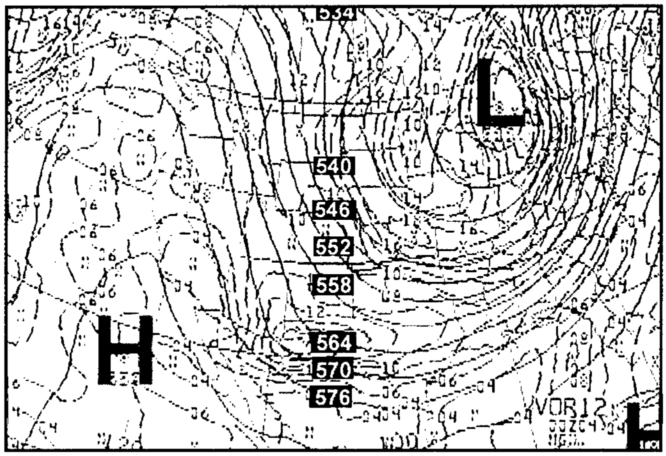

Figure 6-52. 00HR 500 mb HEIGHTS/VORTICITY, 0000Z/4 January 1999

The last set of analysis is shown in Figures 6-52 and 6-53. In the 500 mb analysis, Figure 6-52, the long wave trough is established over the central CONUS. The low continues northward within the long wave. At the surface (Figure 6-53), the coastal low continues northward along the New England coast. The surface low shown north of the Great Lakes is associated with the 500 mb low. With the low north of the Great Lakes, a strong Lake Effect regime has started south of Lake Superior, east of Lake Michigan and also east of Lakes Erie and Ontario.

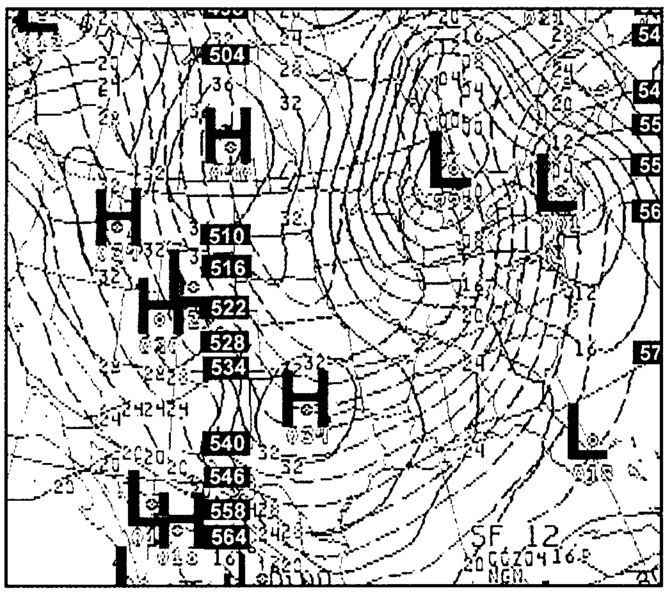

Figure 6-53. 00HR MSL PRES/1000-500 mb THKNS, 0000Z/4 January 1999

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